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The Influence of Islamic Astronomy in Europe and the Far East

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Islam rose very rapidly during the seventh century. From Arabia it spread into Persia, Egypt, Syria, Mesopotamia, Tripoli, Armenia, and Georgia. By the tenth century it had swept westward across north Africa and thence northward into Spain. It reached eastward into Russian Turkestan and downward into north India.

Some historians have looked upon Islam as a wall separating Europe from the Far East during the Middle Ages. Others view it as a bridge or a highway connecting the two, fostering trade and the interchange of ideas. At one time, about the eleventh century, it seemed near establishing a unified culture, if not a political union of Eurasia. The Arabic language became the chief vehicle for the spread of knowledge, including science and specifically astronomy in which we are specially concerned. In general we prefer to think of Islam as a great storehouse into which were gathered and preserved the rich stores of knowledge from the East and from the West, supplemented by local harvests. Filled to overflowing the stores were again spread abroad in all directions and on prepared soil took root and enriched the civilization of Europe and the Far East.

The Islamic ambition of world empire included not only domination but the assimilation of the culture of the conquered races. At the beginning of conquest the Arabs possessed few elements of tradition and culture commensurate with their task. These were gradually assimilated from the civilizations with which they came in contact. Syrians and Copts had considerable influence at first, perhaps overshadowed by the Persians. Then came rich stores from India and China and a little later the more important contributions from the Greeks.

In the primitive culture of the pre-Islamic Arabs, observation of the stars played an important role, as it did in all oriental countries. Directions, time of day, and the determination of the seasons, were regulated by the star-gazers. The twenty-eight lunar stations or zodiacal constellations were known. The heliacal rising and setting of selected stars were observed. Also astrological implications and predictions constituted an important part of the program of the ancient astronomer.

The rise of Islam brought new problems and duties for the astronomer. Determining the direction of Mecca for orienting the Mecca niche in the mosques demanded the services of an expert astronomer, who was also the geographer and cartographer of that period. He also regulated the lunar calendar and determined the dates of the religious celebrations. Then the alluring possibility of interpreting the past or predicting the future by means of the stars kept many astrologers busy at the courts of caliphs and sultans.

At the beginning of the Islamic movement all their learning, philosophy, and science revolved about their religion. Their early educational centers were instituted primarily to propagate their system of theology. Their canon law, however, required some arithmetic, mensuration, geography, and practical astronomy; all of which was subsidiary to their religious system. But the wide conquests and amazing stories from afar inspired the long journeys of the scholars in quest of knowledge, so characteristic of Asia during the Middle Ages. This led to the spread of knowledge and the spirit of eclecticism, which pointed toward an intellectual unity.

Bagdad became the capital and center of culture under the caliphs of the eighth century, a new point of convergence for knowledge, comparable with Alexandria under the Greeks, somewhat broader, however, due to new elements from the East. The Muslim scholars were primarily theologians and historians; so the scientists of these early days were foreigners,—Indians, Persians, Jews, and Christians. A Jew and a Persian laid out the city of Bagdad. At the court of Al-Mansur the Hindu astronomer, Kankah (?), came in 722 bringing books including works by Aryabhata and Brahmagupta. These contained astronomical tables formed on a system of celestial motions somewhat similar to the Greeks, at least geocentric and based on geometrical representations. The chronology was different, containing artificial millenial cycles or kalpas going back many centuries to a hypothetical general conjunction of the sun, moon, and planets. Translations were attempted into the Arabic language, which groped for words to convey scientific content. The Royal Astronomical Tables of the last period of the Sasanids was translated from the Pahlavi and remained in use in the ninth century. Then came the treasures from the Greeks. Syrian Christians attempted the translations at first through Syrian into Arabic.

In the ninth century Islam became the standard bearer of civilization. The caliph Harun-al-Rashid, hero of the Arabian nights, a patron of science, literature, and the arts, in 807 presented a water-clock to Charlemagne. Al-Mamun, who had a Persian mother and a Persian wife, built an observatory at Bagdad in 829 and a little later another in the plain of Tadmor. The instruments, patterned to a certain extent after the Greeks, were larger and superior in workmanship. The astrolabes were not only serviceable in astronomy but were veritable works of art. The Arabs paid more attention to regular and systematic observations than the Greeks and placed more dependence upon measured data and their reductions for practical purposes. In this way improved tables of planetary motions were produced.

Many Greek works were translated, including the Syntaxis of

Ptolemy, which the Arabs christened Al Majisti, *i.e.*, the greatest, and it is still called the Almagest. It is the greatest astronomical work of the ancients, incorporating the so-called Ptolemaic or geocentric theory and other accepted doctrines of the Greek philosophers. Its first translation into Arabic was by Sahl Al-Tabari, a Jew. Other translated Greek works included Ptolemy's Geography and his treatise on the astrolabe, also a work by Aristarchus on the size and distance of the sun and moon. Aristarchus has been called the ancient Copernicus, because he advocated the heliocentric theory, *i.e.*, the doctrine that the planets, including the earth, revolve about the sun.

By observational methods the Arabs verified results given in the Almagest on fundamental astronomical quantities, like the obliquity of the ecliptic, the precession of the equinoxes, the length of the tropical year, etc. The size of the earth was re-determined by the measurement of an arc between Tadmor, Palmyra, and Al Rakka on the Euphrates in Mesopotamia. The result was 56⅔ Arabic miles to a degree (1 mile = 6473 feet) making the circumference of the earth less than 200 miles too large. The great Al-Khwarizmi, who was engaged on the computations, was the first to find time by the altitude of a star, and one of the first to compute trigonometric tables using tangents as well as sines. He also attempted to syncretize Greek and Hindu astronomy.

Even greater was the work of Al-Battani, Latinized as Albategnius, who improved the values of astronomical constants, prepared a star catalogue, made improved tables of the sun and moon, and wrote an astronomical treatise that remained an authority until the sixteenth century. He discovered the motion of the line of apsides of the sun's orbit, or as we would say, a change in the longitude of the perihelion of the earth's orbit. Abul Wafa, latter half of the tenth century, last of the Bagdad school, wrote a voluminous treatise known as the Almagest, not however a translation of Ptolemy.

The Persian, Al-Sufi, prepared an elaborate star catalogue, or Book of the Fixed Stars, Illustrated, closely following the constellations of the Greeks. Some of the star positions were found by new observations. The work was translated into Italian by the astronomer Schjellerup in the nineteenth century. Some of the constellation figures are just as interesting, perhaps more so, from the standpoint of art than of astronomy.

In the meantime a strong school of astronomy developed at Cairo, northern Egypt, under the Fatmid caliphs. The most outstanding astronomer was Ibn Yunos who made regular observations, including several eclipses. He used these data and observations by others in the preparation of the Hakimid Tables, which were the best for two centuries, the eleventh and twelfth. He is especially noted for his method of longitude determination. As time difference is equivalent to longitude difference, the determination of local time at the same instant at two stations widely separated in longitude is sufficient. But there were no telegraph or radio signals to give simultaneity. Ibn Yunos proposed and used a signal from the moon,—the first contact of a lunar eclipse. In this way he corrected many errors in longitude in Ptolemy's geography, *e.g.,* the Mediterranean Sea was seventeen degrees too long.

In Spain centers of learning grew rapidly at Cordova, Seville, and Toledo. Arabic works were translated into Spanish and into Latin, the academic language of the day. The greatest astronomer was Arzachel, second half of the eleventh century, under whose direction was prepared the Toletan Tables in 1080.

We must rapidly pass the work in Persia, where the civil calendar was reformed in 1075. The Persian poet, Omar Khayyam, had the reputation of a great astronomer, chiefly on account of the accuracy of the calendar he proposed. The Sandjaric Tables were prepared in 1118.

Let us return to Bagdad. It was captured and pillaged in 1258 by the Mongul, Hulagu Khan, grandson of the conqueror of China, Genghis Khan. He erected a magnificent observatory at Maragha, near Tabriz, having instruments far surpassing the Greeks. It is said that Chinese astronomers were included on his staff and it seems quite probable that these superior instruments were patterned after the Chinese. Nassir Eddin was the greatest genius of this institution, an astronomer and a geometer. He was quite orignal and independent, drawing of course from Ptolemy, whom he criticized, however, quite severely, paving the way for the overthrow of the geocentric system. The greatest work of his observatory, which required twelve years, was the preparation of the Ikhanic Tables, successor of the Hakimid Tables of Ibn Yunos. A star catalogue was also made, and the precession of the equinoxes was fixed at 51″ per annum, in good agreement with the modern value 50″.2. At the death of Nassir Eddin in 1273 the work at Maragha came to a sudden end.

The last and best equipped of the observatories due directly to Islamic influence was established about 1420 at Samarkand, Turkestan, by Ulugh Beg, grandson of Tamerlane. His greatest work was an independent star catalogue, based entirely upon new observations, the first in about 1600 years, *i.e.,* since the time of Hipparchus, second century B.C. The positions are given to the nearest minute of arc and attained a high degree of precision for that period. His instruments, though entirely lost, are considered the best made up to that time. Here ends the golden period of Islamic astronomy.

Long before its fall, however, its influence was felt in Europe and the Far East. A direct effect was the work in Spain under Alphonso X, who brought together a staff of astronomers and prepared the Alphonsine Tables published on the day of his accession in 1252. He also compiled an extensive astronomical encyclopedia chiefly from Arabic sources. In this work Mercury's orbit is represented as an ellipse; geocentric, of course, but interesting as the first representation of the motion of a heavenly body that departed from the Greek idea of uniform circular motions.

A century earlier, Gherardo of Cremona, who had absorbed all the knowledge of the Latins, visited Toledo and saw the number and quality of the books in Arabic. He mastered the language and translated seventy books into Latin, including some Arabic translations of Aristotle and other Greeks, especially the Almagest of Ptolemy. His work was followed by other translators, so the storehouse in which Greek science had been preserved began to return its treasures to Europe with liberal increase. Many astronomical words have come down to us from the Arabic, *e.g.*, almanac, almucantar, zenith, nadir, also a large number of star names,—Algol, the demon, Altair, Aldebaran, Fomalhaut, the fish's mouth, Deneb, the hen's tail, Betelgeuse, the armpit of the central one, Vega, or more correctly Weki, Arabic for falling, and somewhat erroneously applied to the falling eagle. Science in Europe received a great impetus, not only from this general store, but also by the introduction of the Arabic numerals. The mariner's compass from China also came into Europe and was applied in navigation and exploration. The thirteenth century witnessed the rise of European universities. The one at Naples under Frederick II owed its chief inspiration to the new translations from Arabic sources. The revival of astronomy in Europe during the fifteenth century drew from the same storehouse. Peurbach at the University of Vienna composed his Epitome of Astronomy from poor Latin translations of Arabic and Syrian writings. His more illustrious pupil, Johann Müller, known as Regiomontanus, carried on his work and prepared new tables to take the place of the Alphonsine Tables, then too old for accurate use. A copy of the tables of Regiomontanus for 1490, printed at Nuremberg, is said to have been in the possession of Columbus as he sailed west to reach the east and discovered the new world of America. With the recovery of original Greek manuscripts in astronomy, Europe broke away from its dependence on Islamic sources and the inductive period rapidly developed, chiefly by the contributions of Copernicus, Tycho Brahe, Galileo, and Kepler, and culminated in the *Principia* of Newton.

When Europe was responding to the influence of Islamic astronomy, a similar movement was taking place in the Far East under the great Mongul conqueror, Genghis Khan. The Chinese scholar, Yeh-lu Chutsai, who had just established a large school in Peking, accompanied the ruler to Persia in 1210 and obtained their calendar to use in the Mongul empire. The Observatory at Maragha, founded by a grandson of Genghis Khan, gives further evidence of the close relationship between the Near East and the Far East during the thirteenth century. The next century at Samarkand, the city of the famous observatory, a college was established by the Chinese wife of Tamerlane.

The old Chinese observatory at Peking suffered a severe storm in 1196. Much damage was done to the building and the instruments, some of which were repaired. When the capital was moved to Honan in 1214, the old instruments were left behind, too heavy to be readily moved. The capital was restored to Peking under the Yüan (Mongol) dynasty in 1276, but the old instruments were discarded and new ones substituted. Kuo Shou-ching, under whom this work was done, was a man of genius, an engineer who controlled the floods of the rivers, a master builder and a mathematician. His astronomical instruments were considered equal to those at Samarkand. When Father Matteo Ricci saw some of these instruments at Nanking and Peking, he admired them greatly and said that he had seen nothing better in Europe. He had left Europe, however, at the time Tycho Brahe was just beginning to equip Uraniborg with the best astronomical instruments that preceded the telescope. We saw two of these old Chinese instruments in 1936 at the National Observatory on Purple Mountain near Nanking and it is our opinion that these pre-Jesuit astronomical instruments, reputed to be of thirteenth century origin, not merely equalled but excelled the best made in Europe before the time of Tycho, near the close of the sixteenth century.

Islamic influence in astronomy in China rapidly declined when the Yüan dynasty fell with the rise of the Mings in the fourteenth century. At the beginning of the new dynasty astronomy in China took a backward step. About two centuries later came the Jesuits bringing European astronomy, which had been quickened and enriched by Islam but far outstripped its teachers. Fathers Ricci, Schall, and Verbiest, were favorably received by the Chinese sovereigns, chiefly on account of their scientific knowledge, especially in astronomy. Verbiest in the seventeenth century was accorded the highest position in astronomy in the Celestial Empire, serving as an astronomer royal. Under the Jesuits were constructed the celebrated astronomical instruments mounted on the city wall at Peiping, which are greatly admired by the casual tourist; but the special student of Chinese astronomy looks with greater wonder and admiration at the rare instrumental survivals of the days of close contact between Islam and the Far East.

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Modern Conceptions of the Stellar System*

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Modern astronomical research is concerned with three main problems: (a) Investigations into the nature and constitution of the solar system and of its members; (b) Investigations into the dimensions, the structure and dynamical organization of the stellar system or Galaxy; (c) Investigations into the distribution, distances, and motions of external stellar systems, the extra-galactic nebulae, and into the nature of the Universe. It may safely be said that in the main we have a fairly complete knowledge of the solar system so that this field of astronomical research is limited. Research on the extra-galactic nebulae and on the nature of the Universe has only been intensively followed for about ten years and definite information whether space is flat or curved and whether the four-dimensional space time continuum is expanding will have to wait for much larger telescopes than are at present available.

The second main problem, research on our stellar system or Galaxy, has been for many years, and will probably continue to be for many years more, the major problem in astronomy. While this problem, which is extraordinarily complex and difficult, requiring an enormous quantity of observational data for its adequate study, is still far from a final solution, the earlier rapidly changing ideas of the structure and dimensions of the stellar system have now reached a semi-stationary stage, a stage of only minor changes in the last five years. It is a coherent picture of this stage in the development of conceptions of the Galaxy that I shall attempt to give you in this paper. It must always be remembered, however, that the details of this conception, or model of the Galaxy, possibly even its whole nature, may require radical changes with the advent of new observational data or new methods of treatment.

The plan proposed is partly historical, tracing the increase produced in the dimensions of the Galaxy by the development of statistical methods followed by the sudden enlargement due to the application of luminosity methods in the determination of stellar distances. Corrections for the effects of absorption have reduced these enlarged dimensions so that they are now in agreement with those derived dynamically from galactic rotation. The similarity in dimensions, in constituent membership, and in dynamical constitution between the Galaxy and the largest known external system is the basis finally for a conception or model of the Galaxy as a great discoidal nebula rotating in its own plane and forming a single unified system.

Although there were earlier speculations on the form of the stellar system, Sir William Herschel was the first to apply scientific methods in

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the problem and he may justly be considered the founder of sidereal astronomy. He advanced in 1785, in two papers to the Royal Society, the first definite model of the stellar system, the result of laborious observational investigation of the distribution of the stars. On the assumption of uniform distribution and by means of his 20-foot telescope of 19½ inches aperture, with an eyepiece of power 160 and field of one-quarter of a degree in diameter, he determined the relative distances of the stars in 3,400 regions of known position. This "star gauging" led him to the conclusion that the stars were finite in number and that the system was greatly flattened to the Milky Way with a diameter about five times its thickness. Although Herschel did not know the distance of a single star, he estimated the diameter of the Galaxy as 850 times and the thickness as 155 times the average distance of a first magnitude star, corresponding to about 6,000 and 1,100 light-years, respectively.

The increase in observational data during the nineteenth century led to several attacks on the distribution of the stars in the system, but the next signal advance was recorded by the investigations of Seeliger in the first decade of the present century. Seeliger introduced the conception of a frequency distribution in the intrinsic brightnesses of the stars, and developed expressions connecting the numbers of stars of any given magnitude with the mean parallax and with this luminosity function. These were applied to simplified representations of the stellar system, Seeliger's typical system considered the star density as depending only on the distance from the sun and on the galactic latitude, neglecting the large variations in galactic longitude. The end result was a flattened system similar to Herschel's with the star density decreasing with distance from the sun, the estimated diameter being 7,250 parsecs, 23,000 light-years, with a thickness of nearly 6,000 light-years.

Seeliger's analytical methods were refined and extended by Schwarzschild, Charlier, and others, but the outstanding exponent of the statistical analysis of stellar distribution was undoubtedly Kapteyn, to whom we owe many important advances, notably his plan of "selected areas." Kapteyn used a different method of attack for determining the luminosity and density functions, in which the numbers of stars between successive intervals of apparent magnitude and proper motion, along with the computed mean parallaxes and the frequency function of the true parallaxes around the mean value, were entered in a double-entry table in magnitude and parallax. The luminosity and density functions are obtained from these tables directly, and although they are only valid for distances up to 1,000 parsecs, 3,260 light-years, the density law can be computed for greater distances on the reasonable assumption that the luminosity law is similar throughout the system. The resulting Kapteyn model of the Galaxy is shown in Fig. 1, in which the surfaces of equal density are approximately spheroids, the common axis joining the galactic poles. The diameter, if the limits of the system are fixed at one-hundredth the star density near the sun, is 17,000 parsecs, 55,000 light-years, with a thickness of 3,500 parsecs, 11,000 light-years, and hence with similar flattening to the Herschel and Seeliger systems.

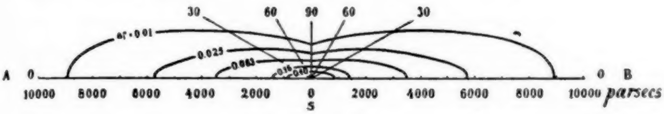

FIGURE 1
KAPTEYN'S GALAXY

All these statistical models are similar in considering the sun as the centre of a watch-shaped system with the star density decreasing outwards. The diameters have increased from 6,000 light-years by Herschel to 23,000 by Seeliger and to 55,000 by Kapteyn, a ninefold increase. The central position of the sun in all these models must have raised doubts about their reality, as the probability of one particular star among thousands of millions of others being central is infinitesimal. Both Seeliger and Kapteyn realized that a very small amount of absorption would completely alter the apparent density distribution, and also that it was impossible to determine whether the observed distribution of the stars was real or due to absorption which could exactly simulate it, and it required a new method of attack on the problem to reveal the partly fictitious nature of these statistical models.

Even before Kapteyn's work was published, a new method of obtaining the dimensions of the Galaxy was developed by Shapley at the Mt. Wilson Observatory, 1916-18, in his investigation of the distances and the distribution of the globular clusters. This method, which has had very important applications, depends upon a determination of the intrinsic brightness of very luminous stars and, hence, by the application of the inverse square law, of their distance. The Cepheid variables, in which the brightness varies with the period, were the principal stars used as distance indicators by Shapley. Although the relation between brightness and period, the period-luminosity law, was well defined, the zero-point, or the intrinsic brightness of a Cepheid of known period, was uncertain, and Shapley fixed this from the proper motions of galactic Cepheids of known periods. These distances were used for the calibration of other methods, such as the median magnitude of the twenty-five brightest stars in the cluster, the integrated apparent magnitude or total brightness, and the angular diameter. In this way Shapley determined the distances of seventy globular clusters, which were found to range between 20,000 and 200,000 light-years.

When the positions of these seventy clusters were projected on the galactic plane, the central position of the sun disappeared; it was near one edge of the cluster system, the geometrical centre being in galactic longitude 327°, in the direction of Sagittarius, where the star clouds are richest. When the clusters were plotted on a plane perpendicular to the Galaxy and passing through the sun and the centre at 327°, the remark-able relation emerged that the globular clusters were symmetrically distributed, with the same number on each side of the central plane, arranged approximately in a spheroidal form. Shapley assumed that this symmetry indicated a dynamical connection between the globular clusters and the flattened central disk of stars, which are hence probably concentric and coterminous. On this basis, the Galaxy was estimated to have a diameter of 80,000 parsecs, 260,000 light-years, and a thickness of some 5,000 parsecs, with the sun 20,000 parsecs from the centre.

Shapley's new and enlarged model of the Galaxy may then be considered as a great flattened disk of stars, star clouds, diffuse nebulae, etc., 80,000 parsecs in diameter, five times larger than the Kapteyn system, with the globular clusters symmetrically distributed and indicating the bounds of the system. The sun has been deposed from its central position in the whole system to the centre of one of the numerous star clouds, so marked a feature of the Milky Way, this "local cluster" being nearer the edge than the centre of the system. The "anthropocentric" density distribution of the statistical models can be reasonably assigned to the fact that the observational data barely extended beyond the local cluster and represented the density decrease in the latter, the extrapolation beyond being vitiated by the effects of absorption. This enlarged and more complex model was generally accepted by astronomers, and in a modified form still holds the field.

The most obvious source of error in the luminosity distances is uncertainty in the intrinsic luminosity of the Cepheids, in the zero-point of the period-luminosity curve. Several determinations of this datum have appeared since Shapley's original value based on the proper motions of a few galactic Cepheids. Wilson in 1923 suggested a correction which would reduce Shapley's distances by 20 to 30 per cent, and Gerasimovic in 1931 from additional proper motions obtained a reduction of nearly 40 per cent. However, Gerasimovic later stated that an allowance for absorption would considerably reduce this correction, while two later investigations indicated corrections between 10 and 20 per cent. It has consequently seemed preferable to adopt the revised distances of ninety-three globular clusters, obtained in 1929 by Shapley and Sawyer, giving a correction to the zero-point of $-0^{M}.23$, reducing the original distances by 11 per cent.

Shapley in his book "Star Clusters," published in 1930, plots anew the distribution of the ninety-three globular clusters, using the revised distances, and this plot is seen in the left-hand section of Fig. 2. On the XY plane, the galactic plane with the sun at the origin and the axis of X passing through the centre, and on the XZ plane, the clusters show a spheroidal distribution and, if some of the clusters are considered as outliers, the longer axis, passing through the centre of the system, has a length of about 60,000 parsecs, the shorter axis of about 40,000 parsecs, while the distance from the sun to the centre is about 16,000 parsecs. Shapley adopts 16,000 parsecs as the distance to the centre but prefers a diameter, as determined from the maximum separation of the clusters, of at least 70,000 parsecs.

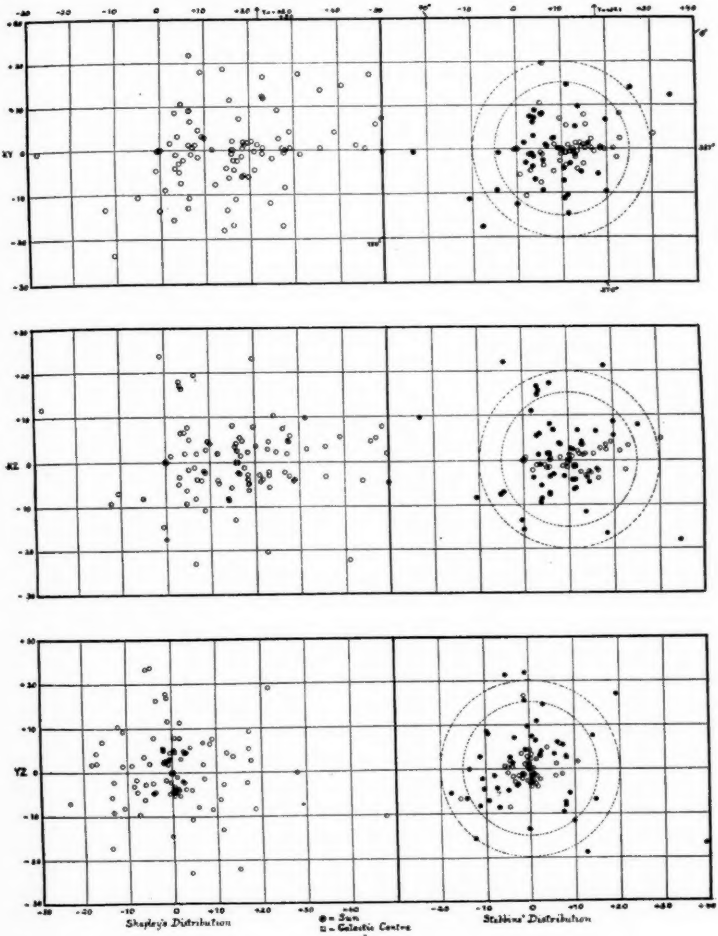

FIGURE 2

DISTRIBUTION OF GLOBULAR CLUSTERS

The great disparity in size between the Galaxy, with a diameter of 70,000 parsecs, 230,000 light-years, and the largest known external system, the Andromeda Nebula, whose diameter according to Hubble was less than 13,000 parsecs, only one-fifth the Galaxy, gave rise to hypotheses by Lundmark, Shapley, and Trumpler, that the stellar system could hardly be a unified spiral system, like the Andromeda and other nebulae, but consisted rather of a loose aggregation of nebulae such as the Magellanic Clouds, N.G.C. 6822, possibly the Andromeda Nebula, and the globular clusters. As will presently appear, recent developments have made these hypotheses improbable and they are no longer serious rivals to the model to be presently developed.

The presence of absorbing material within the system will obviously dim the light of distant stars, and hence distances depending on luminosity methods, based on the period-luminosity law of Cepheids, for example, will be estimated too large. Obviously, therefore, in determining galactic dimensions, the question of absorption, its amount and the effect on luminosity distances, is of extreme importance. Both Seeliger and Kapteyn early realized the effect of absorption on the stellar density distribution, on the apparent central position of the sun, and on the dimensions of the Galaxy in their statistical models, and, with Halm, Schalen, and others, computed the amount of absorption that would make the density distribution approximately uniform, obtaining absorptions varying between $0^{M}.3$ and $2^{M}.1$ per 1,000 parsecs. The difficulty in these determinations lies in the fact that the observed-density decrease with distances might either be real or might be due to the presence of absorption which could exactly simulate it.

These determinations did not appear to be taken very seriously until 1930. This was probably due to the general belief in the effective transparency of space, based principally on Shapley's early investigation of star colors in distant globular clusters at Mt. Wilson. He found blue stars even in very distant clusters, which could not happen with appreciable selective absorption. This idea of transparency of space was strengthened in 1925 by Lundmark, who found, from the variation of surface brightness with distance in extra-galactic nebulae, that the absorption could not exceed $0^{M}.0007$ per 1,000 parsecs. Similarly, Shapley and Ames, from the mean color indices of extra-galactic nebulae, found a maximum selective absorption ten times smaller or $0^{M}.00007$ per 1,000 parsecs, equivalent to a color excess of one magnitude in a distance of 14,000,000 parsecs. These confirmations of the almost complete absence of absorption in inter-galactic space further strengthened the belief that absorption within the Galaxy itself was negligible. Even the known presence of irregularly distributed obscuring clouds in the Milky Way and the observed dark bands in nebulae, seen edge on, hardly affected the general belief in the negligible effect of absorption.

The first direct evidence of a widely diffused gaseous medium pervading interstellar space was given in 1924 in an investigation by the author, who was able to show that the H and K lines of calcium and the D lines of sodium, which were present in the spectrum of every O-type star observed, could not arise in the atmospheres of the stars themselves. They must, therefore, be produced by the presence in interstellar space of once ionized calcium and neutral sodium in a condition to absorb these lines. As a result of these observations, Eddington, in the 1925 Bakerian Lecture, theoretically investigated the properties of this diffuse medium, showing that its density could hardly be greater than 10^{-23} gm/cm^3, and that its effective temperature was about 10,000° K. At this density and temperature, a path of 200 parsecs should produce visible absorption at H and K. It was further shown by me in 1930, in collaboration with Pearce, that the intensity of these lines is directly proportional to the distances of the stars and hence that the diffuse interstellar matter is, statistically at any rate, uniformly distributed throughout the space inhabited by the O- and B-type stars. It must extend, therefore, to 2,000 parsecs from the sun, and hence probably to the confines of the system. Although only the presence of matter giving monochromatic absorption is thereby demonstrated, it seems probable that it will be accompanied by general absorption, or at least, from the known effects of the galactic rotation, that the gaseous matter producing the monochromatic absorption, the H and K and the D lines, and that giving rise to the general absorption are similarly distributed.

The general impression that the effects of absorption within the Galaxy were inappreciable was rudely disturbed in 1930 by Trumpler's investigation on the open galactic clusters. Trumpler obtained the luminosity distances of 100 clusters from the observed apparent magnitudes and spectral types of several stars in each cluster, combined with the accepted absolute magnitudes of these spectral types. If it is assumed that open clusters of the same type have the same linear diameter, the curious relation emerged that the linear diameters of the most distant clusters, computed from their angular diameters and their luminosity distances, were nearly twice those of the nearest ones. As the observational errors cannot account for this disparity, then there must either be an increase of diameter with distance from the sun, a very improbable assumption, or absorption of light in the stellar system. Trumpler found that a photographic absorption of $0^M.67$ per 1,000 parsecs, composed of a selective or reddening part of $0^M.32$ and a general absorption of $0^M.35$ reconciled the disparity. Trumpler believed that the absorbing matter was concentrated towards the galactic plane in a layer 200 to 300 parsecs thick. This concentration explains why Shapley found no absorption effect on the diameters or colors of distant globular clusters, as the effect would be less than $0^M.5$ for latitudes greater than ±8°, over 90% of the globular clusters having greater distances from the galactic plane.

Trumpler's work marked a great increase of activity on the effect of absorption in reducing luminosity distances. Van de Kamp derived an optical thickness of $0^M.8$ and a linear thickness of 210 parsecs for the absorbing layer from the distribution of extra-galactic nebulae and globular clusters, while Seares and Box from statistical researches on stellar distribution obtained absorptions of about $0^M.5$ and $0^M.4$ per 1,000 parsecs. Hubble from the distribution of the extra-galactic nebulae obtained an optical thickness of the absorbing layer of $0^M.5$, that is, the total loss of light in passing perpendicularly through the layer would be $0^M.5$. This would reduce the adopted distance from the sun to the centre of the Galaxy from 16,000 to 8,000 parsecs, while Van de Kamp's distance would be 5,500 parsecs.

These determinations are, however, indirect and uncertain, and more direct measures would be desirable. These were provided in 1933 from Stebbins' measures of the color excess of the globular clusters with his photo-electric photometer attached to the 100-inch Mt. Wilson reflector. Time does not allow a description of the various steps in this process but the final result indicated that the selective optical thickness of the absorbing layer, that is, the reddening of the colors of the globular clusters after passing vertically through the layer is $0^M.18$. As the ratio of total absorption to selective absorption as found by Trumpler and Van de Kamp of $0^M.67/0^M.33$ is practically 2 : 1, the optical thickness of the absorbing layer becomes $0^M.36$. This optical thickness gives, from a table computed by Van de Kamp, a distance of 10,000 parsecs to the center of the Galaxy, as compared to Van de Kamp's 5,500 and Hubble's 8,000. Stebbins, however, preferred to take Shapley's revised distances of 93 clusters, projected on the usual three coördinate planes and plotted to scale on the left hand side of Fig. 2, to apply the correct distance factor corresponding to his optical thickness of $0^M.36$, and to plot these corrected distances on the same planes. This distance factor ranges from 0.25 for latitude 3°.1, the lowest for a cluster, to 0.93 at the pole.

The projection of the corrected distances of the clusters are shown on the right hand side of Fig. 2, those on the left being Shapley's revised distances. It seems obvious that the corrected spherical distribution on the right is much more probable than the spheroidal one on the left. If the clusters are moving in elliptical orbits of various inclinations about the great central mass, the projected distribution should be circular on all three planes as is the case. On the other hand, if the system of globular clusters shares, even in a small degree, in the known rotation of the central disc of stars, while the projection on the XZ plane might be elliptical, those on the plane of the Galaxy, the XY and YZ planes should be circular. That the distribution of the clusters, when corrected for absorption, has a circular projection on all three planes, indicates an absorption correction of the right order, and, indirectly that the globular clusters have no general rotational motion. The distance from the sun to the centre, as obtained graphically from the corrected distribution on the right, is 10,000 parsecs in agreement with that computed on the basis of an optical thickness of $0^M.36$.

It may, therefore, be reasonably concluded that the corrected luminosity method gives 10,000 parsecs as the most probable distance of the sun from the geometrical centre of the Galaxy. There is, however, some uncertainty connected with this value on account of incompleteness in the observational data and doubts of the validity of some assumptions.

An independent method of deriving this distance would furnish a useful check on the rather involved procedure just described, and, if giving results of the same order, would strengthen our confidence in their substantial correctness. Such a method is provided by the rotation of the Galaxy, the distance to the centre being obtained dynamically from the constants of the rotation. Not only the principles used, but the observations employed are entirely different in the two methods, thus providing independent means of deriving galactic dimensions.

Speculations about the rotation of the stellar system around some central body, analogous to the planets around the sun, have been advanced for a century or more, but they were vaguely expressed and failed to give any supporting observational evidence. It was not until 1925-6 that Lindblad, in a series of papers to the Swedish Academy, advanced a definite theory of the rotation of the galactic system, which successfully explained some mysterious systematic motions of the stars. This was followed by Oort in 1927 with a modification of Lindblad's theory which permitted and successfully met observational tests. The theory of the rotation of the Galaxy has become so well known and so generally accepted that it is hardly necessary to give more than a brief summary of the principal features, especially those concerned with a determination of the dynamical distance from the sun to the gravitational centre of the galactic system.

Lindblad assumed that the Galaxy was composed of a number of sub-systems, each in approximate dynamical equilibrium, and each in rotation, though at different speeds, around a common axis perpendicular to the galactic plane. The sub-system with the highest rotational speed will obviously be the most flattened to the central plane, its members will have only small internal velocity dispersion, and will hence move in nearly circular orbits around the centre of mass. The sun, the Milky Way clouds, and the great majority of the stars are members of this greatly flattened sub-system. The members of sub-systems with a smaller general rotational velocity will have higher velocity dispersion, higher apparent velocities; they will move in more eccentric orbits, and be less flattened to the central plane. The "high-velocity stars" are members of a slowly rotating sub-system, their high velocities being simply a reflex of the higher rotational velocity of the sun. Similarly, the preferential direction of motion of the high velocity stars, Strömberg's "asymmetry" is tangential to the circular motion at the sun, perpendicular to the direction to the centre. The globular clusters, with very high velocity dispersion, have negligible rotational motion, move in orbits of high eccentricity and high inclination, and have a nearly spherical distribution. Not only Strömberg's "asymmetry" but the phenomena of star streaming are satisfactorily explained by Lindblad's theory of the rotation of the Galaxy.

It is, however, rather with Oort's development of the rotation theory that we are particularly concerned in obtaining galactic dimensions. On the reasonable assumption that the distance r to the star is small compared with the distance R to the galactic centre, Oort in 1927 developed the following simple relations connecting the rotational effect with the distance position and motion of the star.

$$\rho = r A \sin 2(l - l\ ) \cos^2 b \qquad (1)$$

$$\mu_l = A/4.74 \cos 2(l - l_0) \cos b + B/4.74 \cos b \qquad (2)$$

where

ρ = Radial velocity freed from solar motion, the residual radial velocity.
μ_l = Component in galactic longitude of residual proper motion.
l, b = Galactic longitude and latitude of star.
l_0 = Galactic longitude of the gravitational centre, about 327°.
r = Distance of the star.
A = Radial component of rotation in km/sec per parsec.
B = Average transverse component of rotation in km/sec per parsec.
V = Circular velocity of rotation at the sun.

In addition, we have the simple formula giving the distance to the gravitational centre in terms of the circular velocity and the rotational constants A and B.

$$V/R = w = A - B$$

Oort, from the radial velocities of the most distant objects then available, was able to show a rotational effect varying approximately with the longitude and distance, as indicated by the formula. Moreover l_0, the direction to the centre, was the same, within the probable error, for different groups of stars and, even more significant, agreed with the geometrical centre of the system of globular clusters. It seemed probable, therefore, that the Galaxy was rotating in its own plane, not like a solid body, but differentially, similar to planetary motion, indicating a great concentration of matter to the centre.

The work of Lindblad and Oort had placed the theory of a rotation of the Galaxy on quite a different basis from that of the early speculations. The explanation of star streaming and asymmetry by Lindblad, and the observational confirmation of the differential rotation by Oort, taken in conjunction with the known flattened form of the system, and the spectroscopically demonstrated rotational motion in some extra-galactic systems, had led to its fairly general acceptance. There were, however, some dissentients, and additional observational confirmation seemed desirable.

This was provided by me in 1928 from an analysis of the radial velocities of the "O" and B-type stars, the most luminous, and hence, the most distant readily observable. This was extended later from more extensive material by Pearce and myself. The radial velocities of these distant stars, and of the intervening interstellar matter, followed so closely those that would be produced by a differential rotation of the system in its own plane as to leave few doubts of its presence and to cause the general acceptance of the theory.

The main remaining difficulty lies in the relatively small distance to which the observations of the differential rotation extend. The average distance of the remotest groups used in our tests was about 1200 parsecs although the h and χ clusters in Perseus, about 2,000 parsecs distant, give the proper rotational velocity. However, Miss Hayford has investigated the galactic open clusters to about 3,000 parsecs and Joy the faint and very distant Cepheids to about 4,000 parsecs, both practically confirming the earlier results. By far the most complete and useful are the investigations by Berman of the distance and radial velocities of over 100 planetary nebulae which were arranged into five distance groups at average distances of 850, 2,600, 4,700, 9,100, and 16,400 parsecs. There are, however, so few planetaries in the last group and the velocities and distances are so uncertain, that the data from it were not included in the discussion. With suitable alterations of the rotational formula, required when the distances approach the distance to the galactic centre, Berman showed conclusively that the rotational effect was present at all distances up to 12,000 parsecs with constants practically the same as for the stars. This investigation removed any doubts that the rotational effect observed up to 2,000 parsecs was a local phenomenon and further emphasized the fact that the whole stellar system was a single dynamical unit.

The formula $V/R = \omega = A - B$ or $R = V/(A - B)$ enables the distance R to the gravitational centre to be obtained from the rotational constants A and B and the circular rotational velocity, V, at the sun. The constant A was derived from the value of rA obtained in the solutions of several distance groups of the O and B-type stars, divided by the mean distance r of the groups. The mean value of A, obtained from several groupings of 849 stellar and 314 interstellar velocities, was

$$A = +0.0155 \pm 0.0009 \text{ km/sec/parsec.}$$

This compares with Oort's value of +0.019, Lindblad's of +0.015, and Raymond and Wilson of +0.015, and Berman of +0.014. Although the other constant B can be theoretically derived from A and the ratio of the axes of the velocity ellipsoids, a more direct determination from the proper motions by means of formula (2) above is preferable. In order to obtain reliable values, the exceedingly small proper motions of the very distant O and B-type stars required very careful treatment. First of all, new precessional corrections were obtained, the proper motions were transformed from equatorial to galactic coördinates and the part of the proper motion due to the solar motion removed before the value of B was derived from formula (2).

The value of B, thus derived, of —0.0120 km/sec/parsec agrees well with those obtained from 5,000 Boss stars by Charlier, Fotheringham, Oort, and others with values between —0.008 and 0.012. Oort from the proper motions of 700 distant stars obtained $B = -0.024$ km/sec/parsec. But the larger number and the greater homogeneity of the stars from which the Victoria value was derived and its agreement with those obtained from 5,000 Boss stars entitle it to greater weight, and it was consequently used in obtaining the distance R to the gravitational centre.

In addition, the circular rotational velocity, V, at the sun is required before R can be derived from A and B. This can only be obtained from the radial velocities of distant celestial objects not participating in the rotation and that confines it to the globular clusters and the extra-galactic nebulae. If the globular clusters are considered a sub-system of the Galaxy, then, as the corrected distribution is approximately spherical, there is no rotational flattening and only negligible rotation. If they are considered as having eccentric orbits of varying inclinations, there would also be no general rotational motion so that in either case the velocity of the sun with respect to the clusters when the random motion of the former is removed, gives the rotational velocity of the sun as 272 km/sec. While it is certain that the extra-galactic nebulae have no rotational motion about the Galaxy, the determination of V is complicated by the uncertainty of the red-shift. Hubble, from the radial velocities of 24 nebulae, obtained a velocity of 280 km/sec, and Oort from 53 nebulae, a velocity of 360 km/sec. A rounded value of 275 km/sec, the same as used by Lindblad, has been adopted for the circular rotational velocity near the sun.

With the formula $R = V/(A-B)$ and the value of the constants just obtained, the distance from the sun to the gravitational centre and the period of rotation at the sun are at once derived. The total mass of the Galaxy follows from the application of Kepler's third law by formulae given by Lindblad, and the ratio of the forces from formulae by Oort.

The Radial Component of the Rotation

$$A = +0.0155 \text{ km/sec/parsec.}$$

The Average Transverse Component of the Rotation

$$B = -0.0120 \text{ km/sec/parsec.}$$

The Circular Velocity at the Sun

$$V = 275 \text{ km/sec.}$$

Distance from Sun to Gravitational Centre

$$R = 10{,}000 \text{ parsecs.}$$

Period of Rotation at Sun

$$P = 224{,}000{,}000 \text{ years.}$$

Total Mass of Galaxy

$$M = 16.5 \times 10^{10} \odot.$$

Ratio of Inverse Square Force to Total Force

$$K_1/K = 0.75.$$

The distance from the sun to the centre of the Galaxy, obtained dynamically from the constants of the rotation, of 10,000 parsecs, is of the same order as the values previously obtained. Oort's original determination of 6,300 parsecs was by later developments changed to 10,000 parsecs, while Lindblad's first value of 6,500 parsecs was increased to 9,400 parsecs. The gravitational distance from the sun to the centre of the Galaxy of 10,000 parsecs, from the motions of the O and B-stars, is exactly the same as that dervied from the luminosity distances corrected for absorption. While the exactness of this agreement is probably fictitious, as each determination is subject to considerable uncertainty, the entirely different methods and data, with the unlikelihood that the errors would exactly compensate, serve to give us some confidence in the correct order of this distance. Nevertheless, the radical changes that have taken place in our conceptions of the Galaxy in the past twenty years should tend to discourage any notion that the present conceptions will remain unchanged by future developments.

Even though there may be agreement that the distance to the centre is about 10,000 parsecs, the diameter of the flattened central disk of stars cannot be so definitely assigned. While Shapley appears to consider it to extend nearly as far as the most distant clusters, more conservative opinion might look upon the outermost members as stragglers, and limit the boundary to the position where the clusters begin to condense. Two dotted circles have been drawn around the galactic centre, on the three plots of Fig. 2, of diameters 30,000 and 40,000 parsecs. All would probably agree that the diameter was not greater than 40,000 parsecs, but some would limit it to 30,000, which includes nearly 90 per cent of the globular clusters.

Other methods of obtaining the diameter of the Galaxy may help to clarify the question. Lindblad found theoretically that the sun should be 23 per cent of the radius from the effective limit, making a diameter of 26,000 parsecs. From Trumpler's distances of the open clusters, marking the boundary, the extension beyond the sun is about 5,000 parsecs, making the diameter 30,000 parsecs. Oort finds in his work on stellar distribution that the diameter of the ellipsoid where the photographic light is one-hundredth of that near the sun is 28,600 parsecs. Finally, Shapley gives the luminosity distances of 52 long-period and cluster-type Cepheids in the direction away from the centre, which, when corrected for absorption, indicate an extension of about 6,000 parsecs, making the diameter 32,000 parsecs. The mean of these four methods may be considered as indicating a diameter of 30,000 parsecs. While scattered celestial objects, such as globular clusters, Cepheids, and high velocity stars, extend beyond this limit, the star density so rapidly decreases at 15,000 parsecs from the centre that an effective diameter of 30,000 parsecs may be considered the most probable.

A comparison of this diameter with that of external stellar systems will be of interest. The apparent diameter of the largest known external system, the Andromeda Nebula, is by Hubble's measure nearly 13,000 parsecs, which by corrections for zero point and absorption reduces to about 10,000 parsecs. The original disparity of about six to one has now been reduced to three to one, but is still sufficiently great to leave doubts about the similarity of structure in the two systems even though the demonstrated rotation of the Galaxy indicates its dynamical unity and its similarity to other rotating external systems, including the

Andromeda Nebula. However, some recent investigations have indicated that the Andromeda is nearly double the dimensions earlier given and hence, quite comparable with the Galaxy.

The first by Hubble in 1932 identified 140 nebulous objects in and near the nebula as globular clusters whose distribution indicated a maximum diameter of 30,000 parsecs, but, if the outermost are considered as stragglers, in line with the treatment in the Galaxy, the effective diameter reduces to 20,000 parsecs. Stebbins and Whitford in 1933 from photo-electric measures across the nebula showed that the nebulosity extended much farther than previously supposed and provisionally assigned a diameter of 20,000 parsecs. Similarly, Shapley from density measures of photographs around the Andromeda Nebula showed double the accepted dimensions, or about 19,000 parsecs. These three researches indicate that the diameter of the Andromeda is 20,000 parsecs, two-thirds that of the Galaxy, so that any hypotheses of radical difference of structure in the two systems based on disparity in size falls to the ground. This, taken in conjunction with similarities in surface brightness and membership, points to essential similarity in structure.

A comparison of the surface brightness of the Galaxy and the Andromeda Nebula is difficult, mainly because of uncertainties in the determination of the brightness of the Galaxy. Seares has estimated its brightness near the sun as $23^{M}.7$ per square second of arc and both Seares and Stebbins agree on a brightness of slightly over 18^{M} for the central part of the Andromeda, pointing to a ratio of about 100 to 1. The brightness of the central part of the Galaxy is uncertain as it is largely hidden by obscuring clouds, as well as the general absorption. It seems reasonably certain, however, that the brightness of the Andromeda Nebula, at a point corresponding to the position of the sun in the Galaxy, and hence outside its visible boundary, will not greatly differ from Seares' value and we may hence assume approximately similar surface brightness in the two systems.

The work of Hubble on the Andromeda Nebula has shown the practical identity of membership in the two systems. Each contains stars and star clouds, bright and dark diffuse nebulae, Cepheids, giant and supergiant stars and novae and each appears to be surrounded and outlined by globular clusters. The similarity in dynamical constitution follows from the fact that each rotates in its own plane and, due to this rotation, each has a greatly flattened form and a large and massive central condensation. While the Andromeda has a rather indefinite spiral structure, it is impossible from our position within the central disc of stars to determine the structure of the Galaxy. Both Eastman and Trumpler claimed a spiral structure for the Galaxy, though on rather weak evidence, while Lindblad from his rotation theory considers there may be spiral structure in the outer parts of the Galaxy. However, perhaps the most convincing evidence of the essential similarity of the two systems is obtained by the comparison of a long-exposure photograph of the south preceding part of the Andromeda Nebula with a photograph of the star clouds and nebulosity in Sagittarius. When the difference in scale in the two photographs and the fact that only giant stars show in the Andromeda are considered there can be no reasonable doubt of the similarity in structure of the two systems. When to this is added the similarity in dimension, in constituent membership, and in dynamical organization, there seems little reason to doubt that the Galaxy is a great nebula, probably of spiral form, about ten times the diameter of the average extra-galactic nebula, but only slightly greater than the Andromeda Nebula which it seems to resemble in all essential details.

The dimensions and dynamical organization of the Galaxy having been approximately determined and its essential similarity to the Andromeda Nebula and other extra-galactic systems established, we should now be in a position to construct a model which will include the principal features and conform to the main results of the various researches which have been described in this lecture. It should be remembered, however, that the Galaxy is such a complex organization and so little is known of its structural details, that only the broad features can be depicted in any model, and that not only the details, but even the form and dimensions, may be changed by future developments.

The Galaxy is obviously a single dynamical unit, though of complex structure, and for convenience of description, its main feature, the great flattened disc of stars, containing probably over 90 per cent of the mass of the system, may first be considered. The flattening is undoubtedly produced and maintained by the rotation in its own plane of this disc of stars, which is approximately circular in outline. It has, as we have seen, an effective diameter of 30,000 parsecs, nearly 100,000 light-years, and while the star density rapidly decreases at this limit, there are scattered stars extending to perhaps 5,000 parsecs beyond the boundary. The effective thickness of this flattened disc of stars is relatively small, as from Oort's fine research on stellar distribution, the stellar density decreases to one-tenth that at the sun at a height of 500 parsecs from the central plane, to one-fortieth at 1,000 parsecs and to one-hundredth at a height of 1,500 parsecs. It may, hence, be safely said the effective thickness is not more and probably less than 2,000 parsecs, and this will increase as we go towards and decrease as we go away from the centre of mass. From analogy with external systems, there is probably a spheroidal enlargement at the centre which may be 5,000 parsecs in thickness.

The theory of galactic rotation supplies an explanation for this peculiar distribution of the stars. On this theory, the flattened central disc of stars, containing the greater part of the mass of the system is composed of stars of small velocity dispersion, random velocities of the order of 20 km/sec or less, and includes the sun and the majority of the stars observed. As the rotational velocity is about 275 km/sec with a random motion of 20 km/sec or less, there will be only small deviations from circular motion, and we may assume that practically all the stars within 500 parsecs of the central plane move in nearly circular orbits of small inclination. Remembering that all velocities are measured with respect to the sun, whose orbital motion around the centre is 275 km/sec, it is apparent that in stars with a larger random velocity, and increased velocity dispersion, the departure from circular motion increases and the orbits become more eccentric and more inclined to the central plane. With progressive increase of eccentricities and small inclinations, we have an obvious explanation of the scattered stars observed by Shapley 5,000 parsecs beyond the periphery, while increasing inclinations of the orbit planes will account for those at perpendicular distances of 10,000 parsecs from the central plane. The globular clusters which may have both small and large eccentricities and direct or retrograde motions may have inclinations up to 90° and this will give, as is observed, practically spherical distribution with negligible rotational motion. The observed outlying clusters are probably at the outer apocentric parts of their orbits.

On the other hand, the atomic diffuse matter giving the interstellar lines has a very small velocity dispersion of only about 4 km/sec and the particles, hence, move in practically circular orbits of very small inclination. This gaseous matter must be even more concentrated to the central plane than the stars, the evidence pointing to a thickness of 300 parsecs. It seems reasonable to assume that the general absorbing material has a somewhat similar distribution and that the dark nebulae of the Milky Way are condensations in this general absorbing material similar to the clusterings of stars into star clouds. It is uncertain what proportion of the total mass of the system is due to this absorbing matter, but a layer 30,000 parsecs in diameter, 300 parsecs thick, and of a probable density of 2×10^{-23} gm/cm^3 would have a mass of 6×10^{10} suns. As the total mass of the Galaxy is 16.5×10^{10} suns, 21.3×10^{10} suns according to Berman, the absorbing material, even though its density is equivalent to only three ounces distributed over a cube of 1,000 miles a side, is a considerable fraction of the mass of the system. The work of Edmondson and Berman indicates that the central condensation also carries a considerable fraction of the total mass, one-half according to Berman, and this overcomes the early difficulty that the total mass of the stars was quite inadequate to account for the mass of the whole system.

Before summarizing the principal features of this model a word or two about the dynamics of the system seems desirable. It seems certain, notwithstanding the symmetrical form and the existence of a rotation of the system, that a condition of dynamical equilibrium, a "steady state" has not been reached. The presence of the "local cluster," the Milky Way clouds, and of moving groups of stars is inconsistent with a steady state. It is obvious that the differential rotation would have a shearing tendency on such aggregations of stars and would tend, in a few revolutions, to spread them out into a complete ring. That the local cluster and the Milky Way clouds have not been dissipated in this way shows that other forces must be at work. Strömberg has calculated that, if the mass of a local system is one-hundredth the central mass, it may have a radius one-seventh the distance to the centre without becoming disintegrated at its boundaries.

Summarizing finally the principal features of this concept or model of the Galaxy, we have as the main feature a great central disc of stars, irregularly distributed in groups or clusters, probably with a general

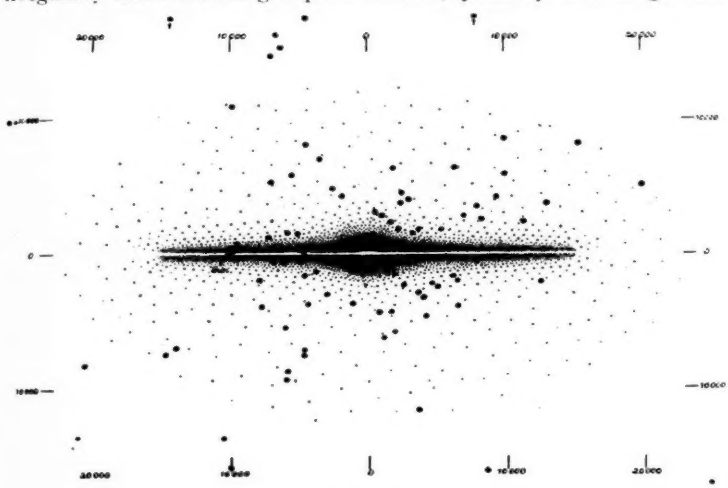

FIGURE 3
PROPOSED MODEL OF THE GALAXY

underlying field of stars and with possible spiral structure. Its effective diameter is 30,000 parsecs and thickness varying between 1,000 and 2,000 parsecs, increasing as the centre is approached where there is probably a spheroidal enlargement of some 5,000 parsecs in thickness in which a considerable part of the mass is concentrated. A stratum of diffuse absorbing matter strongly concentrated to the galactic plane with an effective thickness of some 300 parsecs is dispersed in this disc of stars, this also accounting for perhaps one-third of the total mass. The flattened disc of stars, its central condensation, and the diffuse absorbing material probably account for more than 90 per cent of the total mass. The remainder consists of sparsely scattered stars with high velocity dispersion, such as the M-type and cluster type variables and other high velocity stars and the globular clusters which extend considerably beyond the effective boundaries of the central disk of stars, but probably having an approximately spherical distribution.

In conclusion, while the dimensions, structure, and dynamical organization of the Galaxy have been here fairly definitely stated, the proposed model must be considered only as a preliminary attempt at the solution of this difficult but very important astronomical problem. In view of the changes that have occurred in our conceptions of the Galaxy during the past twenty years, one would be very rash to predict that even approximate finality had been reached. All that can safely be said at present is that the concept developed has a certain unity, completeness, and probability, and it can only be hoped that it makes a useful introduction to more nearly complete knowledge.

Meteor Heights

***Compiled by* HELEN WRIGHT**

On the twentieth of October, 1936, an unusually large Orionid meteor shower was observed at Vassar College. Three hundred and seventy-five paths were recorded. A report of these observations was made in POPULAR ASTRONOMY of December, 1936. Since that time ten more showers have been observed on seventeen nights; including the Orionids, a total of 1723 meteor paths have been plotted and of these 1483 proved to be different meteors. The total numbers obtained for each shower are given in Table I.

TABLE I

	Number of Meteors Observed				
1936	V.C.	V.C.	Smith	New Haven	Mt. Holyoke
Oct. 20	421	374			
Oct. 22	89	87			
Oct. 23	29	29			
Nov. 14	95	95	81		
Nov. 15	20	20			
Nov. 16	53	53			
Nov. 17	216	184	83		
1937					
April 21	55	36	36	13	
May 3	34	32		29	
May 4	39	32		10	
July 10	12	12		10	
Oct. 17	143	118		29	
Oct. 18	16	14		4	
Nov. 15	94	65		96	
Nov. 16	118	68		41	
Dec. 12	180	172		124	128
1938					
April 24	50	49			
Dec. 11	61	43			

In order that the results might prove of greater value it was decided that all observations after October, 1936, should be made in coöperation with some other observatory for the determination of heights. From the American Meteor Society it was learned that Smith College Observatory was at a good distance for such observations. The base line is about 80 miles. Miss Lois Slocum, director of that observatory, agreed to coöperate in the Leonid and later in the Lyrid shower. This coöperative program was later participated in by the New Haven Amateur Astronomical Society under the direction of Mr. Vincent Anyzeski, and finally by a group at the Mt. Holyoke Observatory supervised by Miss Alice Farnsworth. Without the assistance of the three groups mentioned above, the following results would not have been possible; therefore the Vassar Observatory wishes to thank them for their valuable coöperation in the work.

In the computation of heights, Schaeberle's method was used.[1] Al-

TABLE II

HEIGHTS OF METEORS IN MILES

No.	Beg.	End	Mn.	Mag.	Comp.	Date
						1936
1	75	40	58	1	MWM	Nov. 14
2	56	49	53	2	MWM	Nov. 14
3	132	128	130	4	MWM	Nov. 17
4	180	54	117	1	MWM	Nov. 17
5	76	46	61	1	MWM	Nov. 17
6	63	98	80	3	MWM	Nov. 17
7	18	40	30	—1	MWM	Nov. 17
8	50	31	41	2	FF BP	Nov. 17
9	68	51	59	2	KG DR	Nov. 17
10	74	63	58	2	MWM	Nov. 17
						1937
11	50	35	43	—1	A O'N	Apr. 21
12	119	49	84	0	A O'N	Apr. 21
13	58	40	49	—3	MWM	Apr. 21
14	52	47	50	—1	DR	Apr. 21
15	66	50	53	—1	LH HA	Apr. 21
16	41	39	40	—2	DND	July 10
17	42	29	36	—2	BP FF MP PS	July 10
18	89	52	70	3	BC KV	Oct. 17
19	45	17	31	—1	PS	Oct. 17
20	33	31	32	—1	BD MP	Oct. 17
21	65	36	50	—1	MWM	Nov. 15
22	53	40	37	2	MWM	Nov. 15
23	79	35	57	2	MWM	Nov. 15
24	42	48	45	0	MWM	Nov. 15
25	118	99	108	4	MWM	Nov. 15
26	58	73	66	1	MWM	Nov. 15
27	30	36	33	—1	MWM	Nov. 15
28	42	19	30	—1	MWM	Nov. 15
29	65	42	53	1	MWM	Nov. 15
30	120	57	89	1	BD	Nov. 16
31	58	83	70	3	BD	Nov. 16
32	60	55	57	2	MWM	Dec. 12
33	68	60	64	3	MWM	Dec. 12
34	52	48	50	—3	MHW MWM	Dec. 12
35	87	81	84	0	MHW	Dec. 12
36	44	60	52	—2	MHW	Dec. 12
37	64	51	57	—1	MWM	Dec. 12
38	46	46	46	2	MWM	Dec. 12
						1937
39	50	35	43	4	MHW	Dec. 12
40	91	83	87	3	MHW MWM	Dec. 12
41	60	55	57	0	MHW	Dec. 12
42	61	49	55	—1	MHW BP	Dec. 12
43	73	59	66	3	MWM	Dec. 12
44	64	58	61	2	MWM	Dec. 12
45	80	47	63	3	MHW MWM	Dec. 12
46	106	77	92	3	MWM	Dec. 12
47	44	30	37	3	MHW MWM	Dec. 12
48	67	60	64	2	MHW MWM	Dec. 12
49	60	46	53	—1	BP MWM	Dec. 12
50	86	58	72	0		Dec. 12
51	53	64	58	4	BP MWM	Dec. 12
52	94	82	88	4	MWM	Dec. 12
53	59	75	67	2	MHW MWM	Dec. 12
54	36	47	41	—1	BP MWM	Dec. 12
55	43	41	42	0	MHW	Dec. 12
56	46	19	32	—1	MWM	Dec. 12
57	61	60	60	3	MWM	Dec. 12
58	86	56	71	2	MWM	Dec. 12
59	56	12	32	1	MWM	Dec. 12
60	81	57	69	—1	BP MWM	Dec. 12
61	82	40	61	2	MHW	Dec. 12
62	99	40	70	0	MHW	Dec. 12
63	80	54	67	3	MHW	Dec. 12
64	99	51	75	0	MWM	Dec. 12
65	67	51	59	2	MWM	Dec. 12
66	54	116	85	3	MWM	Dec. 12
67	51	51	51	—1	MWM	Dec. 12
68	86	49	68	2	MWM	Dec. 12
69	56	31	43	3	MWM	Dec. 12
70	51	34	43	3	MWM	Dec. 12
71	60	64	62	—1	MWM	Dec. 12
72	82	47	65	3	MWM	Dec. 12
73	40	35	38	3	MWM	Dec. 12
74	55	38	47	—1	MWM	Dec. 12
75	89	36	62	—1	MWM	Dec. 12
76	157	35	96	—1	MWM	Dec. 12

COMPUTERS: H. Albro, B. Cohn, D. Davis, B. Drisler, F. Flanders, K. Gordon, L. Hart, M. W. Makemson, A. O'Neill, M. Peabody, B. Peck, D. Roosen-Raad, M. Spicas, K. Vorhaus, H. Wright.

[1] Olivier, *Meteors*, 1925.

though it is longer, and, perhaps, more rigorous than the observations would warrant, yet it gives a criterion which shows beyond doubt when two observations made at the same instant can or cannot belong to the same object.

From the 1109 meteors observed at Vassar and from a total of 684 observed at the three other stations for altitude determination, 98 heights have been computed. Some of these were observed simultaneously at three different stations and in these cases the mean of the two values for the beginning height as well as for the end height has been taken. In most of these instances the mean heights for the middle of the path checked more accurately than those for the beginning and end heights where the deviations in the results must be attributed to errors of observation. From these observations the probable error for the beginning is found to be 10 miles, for the end 7 miles, and for the mean 5 miles. In addition twelve heights over one hundred and fifty miles have been discarded as unlikely. The revised results are given in Table II.

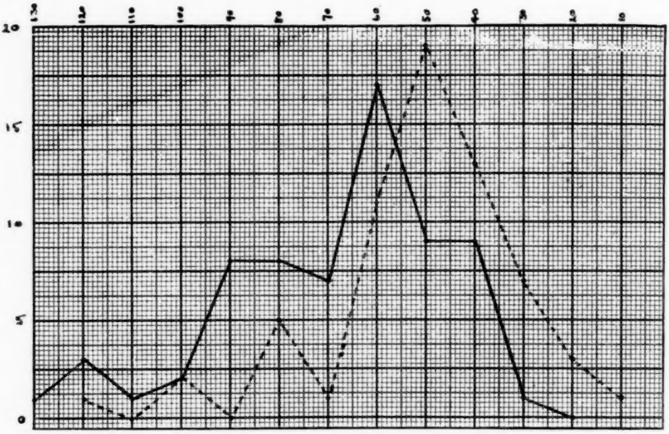

FIGURE 1
Number of Meteors, vertical; Heights (in miles) of Meteors, horizontal.
Full line, Beginning height; Dotted line, End height.

The average height of the beginning and the end for each meteor has also been found as a determination of the height of the center of the path. In a complete analysis of all the meteors computed, the median has been taken. The median of all results for the beginning height is 62.8 miles and for the end height 46.8 miles; this gives a mean height for the median of 54.8 miles. Figure 1 shows the distribution of the meteors recorded in Table II. It will be seen that the greatest frequency for the beginnings occurs at about 60 miles and for the ends at about 50 miles.

In Figure 2 the height has been plotted against the apparent bright-

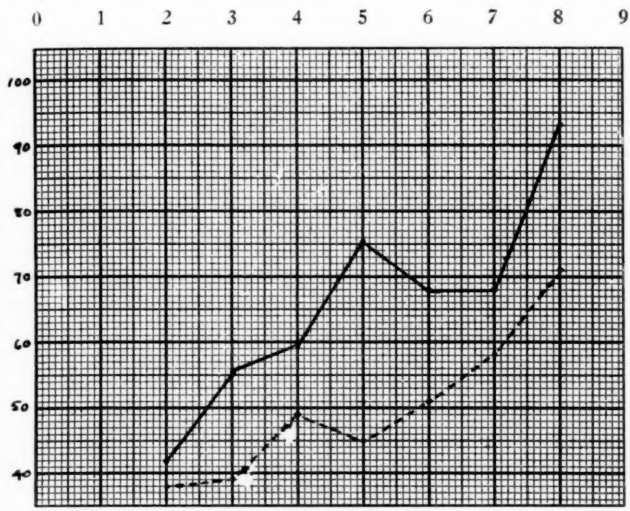

FIGURE 2
Heights (in miles), vertical; Magnitudes, horizontal.
Full line, Beginning height; Dotted line, End height.

ness. The median of the heights of all meteors for a given magnitude is plotted against that magnitude. From the graph there seems to be a definite correlation between the two. The majority of the fainter meteors appear and disappear at a greater level while the brighter ones approach the earth more closely.

OBSERVATION OF METEOR SHOWERS

In the observation of meteors at the Vassar Observatory the following general scheme was followed. Three or more areas, each of which covered about 60° were chosen in the region of the shower radiant and covered the sky to a point 30° west of the pole. Two observers were assigned to each of these areas and a seventh recorded the times of observation to the nearest second. All observations were made from midnight to 4:00 A.M. For the purpose of recording the times a mean time chronometer was used; one observer was then able to check with the observations of the second observer who was recording the same area. At the same time, records of the brightness, duration, and color of each meteor were made. The paths were drawn on the A.M.S. charts, kindly supplied by Dr. Olivier.

The records of color and duration are naturally doubtful; the determination of color is largely a subjective matter, particularly in cases where the meteor is so short-lived. Nevertheless a summary of the general colors observed in each shower will be made and may give some idea of the nature of the meteors observed. As all observers know, the time of duration is the most difficult factor to find in visual observation; it can be really satisfactory only in photographic observations, or with some special rocking mirror apparatus such as that used by Öpik in his work in Arizona. For this reason the individual results will not be given but again a general summary for each shower will be made.

The Leonids

The first shower to be observed for height determination was that of the Leonids in 1936. Observations were made on November 14, 15, 16, and 17. The greatest number seen on any one night was 184 or 46/hr. The maximum was expected to occur on the morning of the 16th, but, owing to drifting clouds, a very small number was actually observed. The morning of the 17th was clear and cold, and, therefore, the best observations of the series were made at that time. When the records arrived from Smith it was found that on that same night 83 had been observed. From these results a total of nine heights was obtained. Previously, on the morning of the 14th, 95 had been recorded at Vassar and 81 at Smith but only two heights could be accurately computed from these results. This small number is probably attributable to inexperience and resulting inaccuracy on the part of the observers at both stations.

The next year, 1937, the Leonids were again observed on the 15th and 16th, but in coöperation with the New Haven Amateur Astronomical Society. Brilliant moonlight on both nights made good observations difficult. The total number seen at both places may be found in Table I. No Leonid observations were made in 1938.

The majority of these meteors were of medium speed and predominantly blue in color.

The Lyrids

Plans were made for the observation of the Lyrids on three nights in April, 1937; unfortunately, two out of the three nights were cloudy. Observations were made on April 21, and even on that night there were drifting clouds so that only 36 meteors were recorded. Smith observed 36. Observations were also made by the New Haven Amateur Astronomical Society. They recorded only 13 paths. From the combined results it was possible to find twelve meteors which had been observed simultaneously at all three places. In this way an interesting check is shown. The Lyrids were, on the whole, quite faint and very fast, but among these there were exceptions and two splendid fireballs were seen during the night. In color they varied from red to blue, and a few yellow ones were also seen.

In April, 1938, another attempt was made to observe the Lyrids. Forty-nine were observed at Vassar but none were seen at either New Haven or Smith owing to cloudy weather. Therefore the results were useless as far as heights were concerned. In color, magnitude, and duration they were fundamentally the same as in 1937.

The Eta Aquarids

The only Eta Aquarid shower observed was in May, 1937. On the 3rd and 4th observations were made. The results, however, were very unsatisfactory owing to two factors. Aquarius itself did not rise until about 3:00 A.M. and, when it did rise, the moon was so bright in that region that very few meteors could be seen. Nevertheless 32 were observed and it is interesting to note that the majority of these must have been sporadic. Observations were also made by the New Haven Amateur Astronomical Society on the mornings of the 3rd and 4th of May, and from these only two heights could be determined. This poor result is probably due to the scattered nature of the meteors observed.

Any color determinations were made difficult, if not impossible, by the presence of the moon. The meteors appeared to be faint and swift.

The Orionids

The Orionid shower in 1937 was disappointing after the display in 1936. The 17th was a very fine clear night and 118 were observed. These meteors were also recorded by the New Haven Amateur Astronomical Society, but only 29 were seen at that station. On the 18th drifting clouds changed to a completely clouded sky so that only 14 were observed. From the first night only 4 good heights could be computed.

As in 1936, the color of the meteors varied from yellow to blue, with the majority appearing to be yellow. The meteors were faint and moved faster than the Leonids.

The Geminids

The Geminids in 1937 proved to be, by far, the best for determination of heights. They were observed on one night only, December 11-12, but excellent observations were made, not only at Vassar, but also at New Haven and Mt. Holyoke. It was clear and cold and the observers had greater experience than in previous showers. 180 were recorded at Vassar, 124 at New Haven, and 128 at Mt. Holyoke. A total of 50 usable heights was found. Of these, 9 were observed simultaneously and, as previously stated, the mean of the two values is recorded in Table II. Therefore 41 heights are tabulated in all.

In 1938 the Geminids were observed on the night of the 11th. Mt. Holyoke had planned to coöperate again, but completely cloudy weather there made any observation impossible. At Vassar 43 were observed in spite of very unsatisfactory weather with moonlight early in the morning and, finally, by clouds which prevented observations after 3:00 o'clock.

It would be interesting to make an investigation of the variation in the heights of meteors for these different showers, but the present material is insufficient (except in the case of the Geminids) for such an investigation. Therefore it is necessary to leave a consideration of this and certain other questions for further observation. It is hoped that the results given above may be of some value in future determinations of the height of the atmosphere and that the work may be carried on by other groups organized throughout the world, so that a more definite knowledge may be gained, not only of the height of the atmosphere, but of its density and temperature, as well as of the origin of the different classes of meteors.

VASSAR COLLEGE OBSERVATORY, JANUARY, 1939.

Planet Notes for June, 1939

By R. S. ZUG

NOTE: Greenwich Civil Time is employed unless otherwise stated. To obtain Eastern Standard Time subtract 5 hours, Central Standard Time, 6 hours, etc. The planetary phenomena are described as they are to be seen from latitude 45° N. The data are taken chiefly from the *American Ephemeris and Nautical Almanac*.

Sun. The apparent positions of the sun for June 1 and June 30, respectively, are: $\alpha = 4^h 31^m 8$, $\delta = +21° 53'9$; $\alpha = 6^h 31^m 9$, $\delta = +23° 14'5$. The sun in its apparent motion proceeds through the constellation Taurus until June 21, when it enters, and for the duration of the month remains in, the constellation Gemini. Summer begins on June 22, $7^h 40^m$, at which instant the sun is at the summer solstice, the northernmost point of the ecliptic. Values for the equation of time are as follows:

Date 1939	Equation of Time (Mean - Apparent) m s	Date 1939	Equation of Time (Mean - Apparent) m s
May 31	— 2 38	June 16	+ 0 15
June 4	— 2 2	20	+ 1 7
8	— 1 21	24	+ 1 59
12	— 0 35	28	+ 2 50

Moon. Phenomena of the moon will occur as follows:

		h m
Full Moon	June 2	3 11
Last Quarter	10	4 7
New Moon	17	13 37
First Quarter	24	4 35
Apogee	7	23
Perigee	19	20

Mercury. Mercury will be in superior conjunction with the sun on June 7, after which it will be an evening star, but too near the horizon to be easily located.

Venus. Venus is located in the morning sky and, in its apparent motion, is gradually drawing nearer the sun. The following data are taken from p. 33 of POPULAR ASTRONOMY for January, 1939:

Date 1939	Distance from Earth (Miles)	Angular Diameter	% of Disk seen Illuminated	Stellar Magnitude
June 1	138,190,000	11"3	90	—3.3
July 1	149,350,000	10.4	95	—3.3

Venus will be in conjunction with Uranus on June 5, 9^h, when it will pass 1°2 to the south of the latter planet. A conjunction of Venus with the waning moon will occur on June 15, 21^h, when the moon will pass a degree to the south of the planet.

Mars. Mars will be situated in the constellation Capricornus, and will rise a little before midnight during June. The planet is moving slowly eastward until June 24, when the apparent motion becomes retrograde. The brightness of the planet will be more than doubled during June. Data of interest to observers are as follows:

Date 1939	Distance from Earth (Miles)	Angular Diameter	Stellar Magnitude
June 1	55,310,000	15".7	−1.2
15	51,196,000	18.3	−1.5
July 1	40,776,000	20.3	−2.1

Jupiter. Jupiter is situated in the constellation Pisces, just east of the vernal equinox, and is in slow eastward apparent motion. The stellar magnitude is —1.8 on June 1, and —2.0 on July 1. The planet will be in western quadrature with the sun June 30.

Saturn. Saturn will be a morning star of magnitude +0.7 during June, situated in the constellation Pisces. This planet, together with Venus, Mars, and Jupiter, will provide a brilliant array of morning stars during the early summer months of 1939.

Uranus. Uranus is also a morning object during June, and is to be found in the constellation Aries. The positions of the planet for June 1 and June 30, respectively, are: $\alpha = 3^h 7^m.0$, $\delta = +17° 12'.0$; $\alpha = 3^h 12^m.9$, $\delta = +17° 35'.4$. The stellar magnitude will be +6.2, and the angular diameter 3".3, during June. On the morning of June 5, Uranus will be located 1°.2 directly to the north of the planet Venus. An occultation of Uranus by the moon is predicted for June 15, $0^h 24^m$.

Neptune. Neptune rounds the western end of its annual loop of apparent motion on June 2. Thereafter, its motion during June is to the eastward among the stars (direct). For aid in locating the planet in the evening sky, the chart of the planet's apparent path among the stars, which appeared on p. 36, of the January issue of POPULAR ASTRONOMY, may be found helpful.

Occultation Predictions

(Taken from the *American Ephemeris*)

OCCULTATIONS VISIBLE IN LONGITUDE +72° 30′, LATITUDE +42° 30′.

Date 1939	Star	Mag.	IMMERSION Greenwich C.T. (h m)	a (m)	b (m)	Angle E from N (°)	EMERSION Greenwich C.T. (h m)	a (m)	b (m)	Angle E from N (°)
June 5	ρ Sgr	4.0	2 33.4	−0.8	+2.2	59	3 37.1	−0.8	+0.8	292
6	16 B.Cap	6.2	9 15.4	−1.3	+0.8	42	10 31.5	−1.8	−1.2	273
6	β Cap	3.2	9 23.5	−1.4	+0.6	47	10 41.4	−1.7	−1.1	268
20	BD+14°1850	6.4	0 37.5	−0.2	−1.2	94	1 29.1	+0.2	−1.6	300
22	14 Sex	6.3	0 33.2	−0.4	−2.3	146	1 25.6	−0.7	−1.2	261
26	86 Vir	5.8	3 26.4	..	..	35	3 49.9	..	..	358
29	χ Oph	4.6	1 11.1	−1.2	−0.9	144	2 11.7	−2.4	+1.3	237

OCCULTATIONS VISIBLE IN LONGITUDE +91° 0′, LATITUDE +40° 0′.

Date 1939	Star	Mag.	IMMERSION Greenwich C.T. (h m)	a (m)	b (m)	Angle E from N (°)	EMERSION Greenwich C.T. (h m)	a (m)	b (m)	Angle E from N (°)
June 4	89 G.Sgr	6.5	10 15.5	−1.7	−1.2	98	11 26.3	−0.6	−0.1	232
6	16 B.Cap	6.2	8 45.0	−1.5	+2.4	25	9 50.9	−2.9	−1.3	295
6	β Cap	3.2	8 52.2	−1.5	+2.1	30	10 3.8	−2.8	−1.1	289
26	86 Vir	5.8	2 44.8	−2.4	+0.5	61	3 39.0	−1.2	−2.8	339

Occultations Visible in Longitude +120° 0′, Latitude +36° 0′.

June	4	89 G.Sgr	6.5	9	13.0	—2.4	+0.5	83	10	46.7	—2.2	0.0	256
	6	10 B.Cap	6.2	7	46.7	—1.5	+3.5	25	8	36.9	—1.6	—0.6	310
	6	β Cap	3.2	7	53.9	—1.5	+3.3	28	8	48.8	—1.7	—0.4	306
	12	ε Psc	4.4	10	10.9	—0.2	+1.5	79	11	12.5	—0.4	+1.9	236
	26	86 Vir	5.8	1	37.8	—1.7	0.0	113	3	0.4	—1.8	—0.7	299

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

Hardly had I mailed the annual report when the delayed regional reports from the Missouri-S. Illinois and Wisconsin-N. Illinois groups arrived. These are now included in this supplement, which as will be seen has 6985 meteors to add to the 9243 in the main report, increasing the latter 76% to a grand total of 16,228 observed meteors. My remarks, particularly about the former group, hence would be wholly without justice except that I had not received the report on time and had not been kept informed during the year of the activities of the group. It now turns out that J. W. Simpson, before the session started in September, had already broken his personal record for any single year and that several of his colleagues had done extensive and noteworthy work, as will be seen from the table. I therefore apologize most sincerely for my expressed fears that Simpson's departure had stopped the activity of the group. I hope to be able shortly to announce the name of his successor as regional director. May he be able to maintain the high standard of activity the Missouri-S. Illinois group has maintained during recent years! Even now I have but a partial report from the Milwaukee-N. Illinois group; more observations were made by them which have not come to me. The additions to Loreta's totals are due to one of his reports being mislaid here, not to his delay in sending it. We are also glad to have received records of 26 more telescopic meteors. The few belated accounts of fireballs for 1938 that have recently come in will be kept until next year and then added to the total.

Several years ago Mrs. Doris Wills of my staff undertook to find all errors and omissions on the meteor charts, originally designed by R. K. Young, and for over two decades distributed to A.M.S. members and others. E. A. Halbach of Milwaukee, one of our most active members there, undertook to make new plates for these charts incorporating the corrections. This he did some time since. The A.M.S. has now ordered and just received from him 1000 each of charts 1 to 13 inclusive. The use of these will eliminate the troubles due to the errors in the originals, though in fact most of these errors were rather small. Halbach is to be heartily commended for carrying out a difficult task undertaken purely for the love of science, and our results will consequently be more nearly accurate.

Some months ago I thought it proper to discuss at some length and rather critically the recent important work of the Harvard Arizona Meteor Expedition, in so far as it referred to radiants. (See *P. A.*, **46**, 325-328, 1938.) Professor E. Öpik has just written me in reply and I publish his letter, as requested, in full. At a later date I may make some further remarks upon the subject. But now I am most happy to comply with his request, first because I think his writing to me directly a courteous and ideal way of handling such a matter, for it keeps it out of unpleasant controversy. Secondly because his letter clears up for me, and doubtless will for others, some points in which I did not fully understand his meaning and hence was unduly critical. Everyone of course knows he is one of the leading authorities in the world in meteoric astronomy and what he says deserves most careful attention. Just because there were some differences of opinion between us does not in the least lessen my regard and respect for the great work he has done and is doing in the subject. All of us are seeking the truth only; it however has seemed at times that different methods of approach were more suitable or more nearly accurate.

SUPPLEMENTARY REPORT OF 1938

	Nights	Meteors
Simpson, J. W., Baytown, Texas	122	3614
Zahner, D. D., Webster Groves, Missouri	78	1597
Friton, E. E., St. Louis, Missouri	11	254
Seune, J. H., St. Louis, Missouri	13	149
Brueggemann, H., St. Louis, Missouri	10	138
16 observers, near St. Louis, Mo., & at Estes Park, Colo.		818
All above are members of the Missouri-S. Illinois group.		
Halbach, E. A., Milwaukee, Wisconsin, reporting for 12 observers of the Milwaukee Astronomical Society	1	163
Loreta, E., Bologna, Italy, additional report	20	226

TELESCOPIC METEORS

Simpson, J. W., Baytown, Texas	8
Zahner, D. D., Webster Groves, Missouri	6
Hildom, A., Los Angeles, California	5
Houston, W., Milwaukee, Wisconsin	2
Loreta, E., Bologna, Italy	5
Total	6,985
Original Report	9,243
Revised Total	16,228

Flower Observatory, Upper Darby, Pennsylvania, 1939 March 23.

DEAR DR. OLIVIER:

Thank you very much for *Flower Observatory Reprint* No. 46, Meteor Notes. I find there criticisms referring to my work connected with the Arizona Expedition: may I ask your favor of including the present letter into your coming Meteor Notes, in order that more clearness may be attained and justice done to the case. I would have replied much earlier, but somehow this particular issue of the POPULAR ASTRONOMY did not come before my eyes. Also, I should appreciate very much the complete reproduction of the present letter, because quotations and abbreviations may change the meaning.

In the June-July issue of POPULAR ASTRONOMY, 1938, your criticisms are concerned with my paper on meteor radiants in *H.C.O. Circular* No. 388. Let me reply to the most important points stressed in your note.

The above mentioned investigation consists of two principal procedures: the determination of the position of radiants, and the calculation of their probability of reality. The determination of the position of the Arizona radiants was performed by me by a graphical method which is identical with the generally adopted procedure used by Denning, by you, and by other recognized workers; as described on pp. 4-5 of my paper, the method consists in looking for the crowding of intersection points, and in applying *personal judgment* to determine the most probable position of the radiant. No new mathemtical method was introduced for this purpose: thus, your opinion that certain errors in the deduced positions of the radiants are explained by "a purely mathematical way of treating data" is based upon complete misunderstanding of what I actually did.

The *positions* of the Arizona radiants are not very accurate, nor were they supposed to become accurate, as clearly stated at many places in my paper; the inaccuracy, however, is not due to "an inferior method of observing," but to the arrangement of observations for general statistical purposes: these required the observations to be arranged in fixed zenith distance and azimuth. It is well known that the error in the position of a radiant increases with the average angular distance of the observed meteors from the radiant; when an observer looks for an already known radiant, he chooses the region of observation as close to the radiant as possible, working thus mostly with an average distance of only 20°; on the contrary, for fixed areas of observation like those of the Arizona Expedition, the average (probable) distance of a meteor from its radiant is 60°; the error in the position of a radiant, for equal quality of observation, is thus $(\sin 60°/\sin 20°) = 2.5$ times larger in the case of the Arizona areas, as compared with special observations of a particular radiant: the actual error is still larger, because with the smaller resolving power due to the above-mentioned influence of pure errors of observation, the influence of stray meteors increases, influencing thus personal judgment. I find it unfair to judge the soundness of a plan of observations from results for which the plan was not meant for. A different plan of observation might have added the one-thousand-and-first accurate radiant to the one-thousand former radiant determinations of well-known meteor streams, but the kind of information which I wanted to get would have never resulted from such a repetition of old methods. The Arizona radiants are a by-product in observations arranged for a different purpose and, as such, they are satisfactory enough.

Another point refers to the accuracy of observations with reticles. One-quarter of the Arizona observations were made at the rocking mirror apparatus, without reticles, by tracing meteors in the usual manner on star-maps; these observations were not more accurate than the reticle observations of the same observers—on the contrary. The writer himself has two series of velocity observations to compare: one, obtained in Arizona by using star-maps; the other, at Tartu (soon to be published), referred to a reticle; the reticle observations, as judged from meteors belonging to the well-known showers, yield only one-half the probable error, or a quadruple weight as compared with my own star-map observations. Besides, the reasons why the requirement of statistical completeness might have increased the observational error for the average Arizona observer, are mentioned on p. 7 of my paper. Further, the impossibility of use of a ruler with the adopted device has doubtlessly diminished the accuracy of the observed directions.

The second procedure, which is the new and the most important one in my paper, is the determination of the probability of a radiant *after its probable position is fixed by the usual graphical method.* I cannot see why you object to the procedure, as its application does not change a line in the list of radiants already obtained. There does not exist up to present, as much as I know, another method (certainly no graphical method!) to calculate the probability of reality of a radiant. If I did not publish the remaining 1720 Arizona radiants for which the probability of reality was too low, it does not mean that all this material is to be finally rejected; on the contrary, I find useful application for it, too. It must be stressed, however, that a radiant with an unsatisfactory position may have a high probability of reality; the inaccurate position cannot serve to deny my method of calculating probabilities; if the position is not accurate enough, the high probability indicates that at or near the supposed point a real radiant must exist; special observations may help later to fix the accurate position of the radiant; such a knowledge of reality of an "inaccurate" radiant is certainly of greater value than an accurate position of a spurious radiant.

A number of quotations from my paper, in which you apparently find a disproval of all former work done, must be based upon a misunderstanding as was the case with the positions of the radiants. On p. 2 I clearly state: "We do not wish to imply that the former work on radiants is futile." On the contrary, I would suggest that with some large series of observations, perhaps with the A.M.S. results of your own, he tried the determination of the probabilities of reality; for this purpose, with the unchanged positions of the radiants as they are already published, one must go back to the original maps and measure the deviation in angle, ΔA, of the observed direction from the "theoretical" direction. The methods can be applied, of course, only to such maps where the *observer* did record practically every meteor, or, at least, where the reason of not including some meteors was independent of the observed direction. Everyone, who has dealt with probabilities, knows that this requirement is a necessary condition. My remark that "observations are unusable (for the calculation of probabilities, not for the determination of positions! E.Ö.) when some observed meteors were arbitrarily rejected because they did not agree with the observer's expectation" refers evidently to the observer, not to the computer of the position of the radiant: the latter has to use his personal judgment, and so did I also. Now, the A.M.S. observations should answer very well to this requirement; from the *A.M.S. Bulletin* No. 15, Instructions, I cite: "If possible, record all meteors seen during the observing period." Thus, a faithful observer who followed these instructions, must have collected material which allows of a determination of the probability of radiants derived from his observations. I am sure that the A.M.S. records contain a large and precious material from this standpoint also, and that the probabilities of the radiants published by you can be derived from the original maps. Let me also ask now in all fairness—why not to try these additional computations, in order to increase more the value of the valuable work? If needed, I am ready to help. If the observations are more accurate with respect to direction, as compared with the Arizona observations, the calculation of probabilities should give a greater "statistical resolving power," a sharper margin for the probabilities, and a greater percentage of real radiants.

Further, you say my term "group radiant" is "only a play on words"; this should be again only a misunderstanding; a careful reading of the second page of my paper should manifest the necessity of such a special term, applied to a common radiant of a whole system of heavenly bodies, contrary to the individual radiant of one single object; the latter is always unquestionably real, whereas the former may be not. "Group radiant" means thus exactly the same what you call simply "radiant." I never did mean to design something different by it.

From the above, I hope, it appears that it is possible to reconcile old methods with the new analysis, and that it is highly desirable to apply to the A.M.S. observations of radiants the methods of analysis of probabilities which, after all, are not as "mathematical" as they appear at the first glance; we must not forget that probability is the only reality in the universe.

With my best wishes, very truly yours,

Ernst Öpik.

Tartu, Estonia, March 7, 1939.

Contributions of the Society for Research on Meteorites

Edited by FREDERICK C. LEONARD,
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President of the Society: H. H. Nininger, Colorado Museum of Natural History and American Meteorite Laboratory, Denver
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The Monahans, Texas, Meteorite

By H. H. Nininger

Abstract

The Monahans, Texas, meteorite seems to form a connecting link between the group of the nickel-rich ataxites and that of the finest octahedrites. It has developed an unusually heavy crust of oxides in which zaratite has been identified. It is thought also to contain diamonds. A chemical analysis, showing 88.30% Fe and 10.88% Ni, by F. G. Hawley, is included. [See also the following paper by J. D. Buddhue.]

This interesting meteorite was found in a sandy region about 7 miles S.S.E. of Monahans, Ward Co., Texas, in the summer of 1938. It is one of the few meteorites which have been dug out from below the surface of the ground, yet located without the aid of the plow. Mr. M. P. White of Monahans, who found the mass, reports that he was attracted to a brown patch on the sand. On closer inspection, the color was found to be due to an abundance of brown rust-scales mixed with the sand. Upon digging to ascertain the source of these scales, he encountered the meteorite at a depth of about a foot.

According to Mr. White, the mass weighed 65 lb. when found. When it reached the laboratory, however, the weight was 61.5 lb. This discrepancy is due in part, doubtless, to the loss of a considerable portion of the oxide scale in which the mass was incased. This scale formed a shell varying in thickness from ¼ in. to ½ in. over the entire mass. Mr. White had discovered the metallic core inside this shell, and, in sending samples for testing, had included a piece of the scale and also a small piece of the metallic core. The junction between the oxide and the inclosed metal is in this meteorite very distinct and they separate rather easily. When the shell is broken away, the unoxidized core appears fairly fresh and comparatively free from scale. A little rubbing of the exposed core with burlap reveals many points of white metal. It is possible that the original size of the meteorite had been considerably reduced by the sloughing off of scale, but the texture and the general appearance of the surface indicated that not more than a few hundred grams had been lost to the soil before the specimen was found by Mr. White.

A conspicuous feature of the mass was a wedge-shaped fracture extending entirely through it except for about 3 sq. cm. at one corner. This fissure divided the mass approximately in halves; it was filled with oxide, which appeared to be of the same composition as that which covered the outside. The width of the fissure was 8 mm. at the base and gradually diminished to zero near the opposite corner of the iron. A wedge was inserted and, by means of a mechanical press, the specimen was divided along the fissure. During the process, the oxide shell fell away in large sections like the husk of a hickory or a pecan nut. Where the unoxidized metal was torn by this process, it resembled a break in armor plate. The alloy, though malleable, broke with little bending. The grain was fine and rather uniform. In cutting 7 slices off of one of the halves, only 2 nodules of troilite were encountered and no visible inclusions of schreibersite were noticed. The polished section shows a uniformly compact structure which takes a high polish.

FIGURE 1

A SLICE OF THE MONAHANS METEORITE (NATURAL SIZE) SHOWING: (A), the tendency toward, or incomplete, octahedral crystallization; (B), one large nodule of troilite and several smaller ones; (C), Reichenbach lamellae; and (D), the oxidation proceeding from the edge of the slice.

Upon etching, the bright luster gives way to a dull gray, but the surface does not darken noticeably, as does that of Babb's Mill, Tennessee, Tlacotepec, Mexico, or Piñon, New Mexico. Rhabdite needles are very scarce; this fact is in harmony with the low phosphorus content. Examined under a ×10 lens, the etching pattern of this meteorite is most interesting and unusual. It appears to represent a transition from the nickel-rich ataxites to the finest octahedrites. Viewed casually from a little distance, it appears as a dull gray surface with abundant patches of a lighter gray which, in certain lights, present a somewhat silvery appearance. If inspected at close range with the light coming from the side at a low angle, the surface presents a multitude of short, indistinct, interlacing, straightish lines which suggest, but never quite conform to, the typical Widmanstätten pattern of a finest octahedrite. The more conspicuous of these lines consist of spindle-shaped kamacite inclusions, each bordered by a prominent ridge of taenite, the latter averaging approximately half the thickness of the former. Associated with the spindle-shaped kamacite plates (which must be in reality in the form of lenses), is a confusing network of tiny ridges of taenite. These often arise in connection with the larger ones just mentioned. In fact, it seems that the taenite-kamacite associations described, constitute centers from which this minute reticulum grew. These ridges diminish in size as they recede from their origin until they disappear altogether.

Apparently, we have here an example of a meteorite which had its origin in a magma which was too rich in nickel to allow for the complete development of the Widmanstätten structure, but which tended strongly in that direction. The nickel content of 10.88% is slightly below that characteristic of a nickel-rich ataxite, but distinctly above that recorded for any well patterned octahedrite. On each slice are found a few lines of a different type; these appear to consist of 2 parallel plates of taenite between which may lie a thin sheet of troilite. The latter is sometimes missing, however. These lines probably represent poorly developed Reichenbach lamellae, and they do not conform in their arrangement with the first group. Their arrangement suggests that of Neumann lines, but they are too few in number to admit of such a generalization.

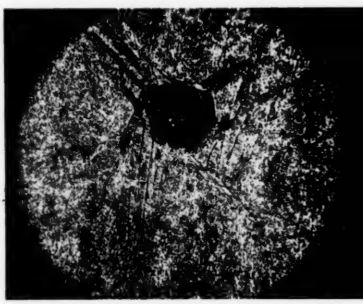

FIGURE 2

THE MONAHANS METEORITE

An area showing a nodule of troilite in a matrix which has developed several good crystals. The kamacite is traversed by Neumann lines and is bordered by narrow taenite bands (×12).

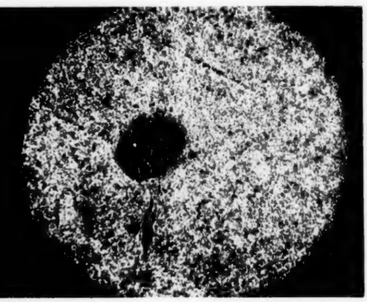

FIGURE 3

THE MONAHANS METEORITE

An area showing a small troilite nodule in a matrix of nickel-iron, which shows but a slight tendency toward crystallizaton (×12).

Scattered throughout the metallic alloy are numerous small inclusions of troilite, usually less than one millimeter in cross-section. These vary in form, but are for the most part four-sided, well-formed rectangles. A few are hexahedral and some are oval or circular. In 3 of the 7 cuts made, large troilite inclusions were encountered. The one shown in the illustration (Fig. 2) is bordered by a narrow kamacite plate lying between two thin sheets of taenite, the assemblage measuring scarcely 0.1 mm. in thickness.

Diamonds Probably Present

In grinding 2 of the 7 slices, the revolving carborundum-cloth disks were several times grooved by protruding objects which we were never able to find. The grooves would rapidly grow deeper as the grinding continued and, after a few turns, the cloth disk would be cut through. After a slit 6 in. to 12 in. in length had been formed, the cut would end abruptly. We were never able to stop the grinding at the right instant to locate the cutting agent; but we suspected that small diamonds were responsible. Carbonadoes (black diamonds) have several times been encountered in our laboratory while preparing specimens of the Canyon Diablo, Arizona, irons. In those cases the grooves would appear and continue to form for some time, but the disk would seldom be cut through for the reason that a carbonado is granular and will crumble under the pressure of the revolving disk. When the white streaks caused by the grooving of the carborundum would appear, we could note its location in the slice and, by an examination, locate even small carbonado inclusions. In the case of the Monahans iron, however, the cutting was much more rapid and complete. We suspect that in this case there were minute crystalline diamonds instead of the granular aggregates in Canyon Diablo; because Monahans is a softer alloy, it grinds much more rapidly, doubtless allowing the small diamonds to be exposed and dragged out before we are fortunate enough to find them. A crystal 0.3 mm. in diameter would have been sufficient to cut through the disks which were used. Subsequently, a more extended search will be made for diamonds in this meteorite.

A chemical analysis was made by F. G. Hawley, with the following results:

Fe	88.30%
Ni	10.88
Co	0.63
Cu	0.69
Cr	0.021
Mn	trace
P	0.093
Si	0.01
S	0.047
C	trace
Total	100.67

This shall be called the Monahans, Texas, meteorite. Its location is approximately long. W. 102° 55′, lat. N. 31° 50′.

The Oxide of the Monahans, Texas, Meteorite

By John Davis Buddhue,
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Abstract

The Monahans, Texas, meteorite belongs to the Cape Group of ataxites and was discovered from the rust stains in the sand above it. The meteorite was inclosed in a loosely adherent oxide crust. The metal core was almost divided in halves by a deep fissure. When this fissure was completed, a fracture like that of armor plate was produced, although the metal is malleable. Etching produces a dull but not a very dark surface, with indistinct irregular patches visible at certain angles. Some slices produced cuts in carborundum-cloth grinding disks. It is believed that these cuts may have been produced by small diamonds. The rust is blackish-brown, lamellar, and magnetic, and has a specific gravity of about 3.1. It contains some residual metal and consists of 2 bodies with the same structure as

the metal. A green stain is probably zaratite. A chemical analysis of the oxide crust is given and shows that the crust has lost some of its nickel. Tap water dissolves still more material, but this is possibly lawrencite. [See also the preceding paper by H. H. Nininger.]

This oxide forms a coating approximately 1.5 cm. in thickness on the surface of the iron. It is compact in part, and grades into distinctly lamellar areas. The general color is blackish-brown, but on fresh fractures is bluish-black. The oxide contains a number of narrow cracks, some of which are of considerable depth. In my sample, these tend to run parallel, so that the fragments are long and narrow. It is strongly magnetic. The specific gravity of 4 large masses ranged from 3.70 to 4.20. The other 2 specimens gave 3.085 at 27° C. These values are probably slightly low, as it was very difficult to remove all the air bubbles.

A considerable amount of solution and redeposition of the oxides seems to have taken place. The exterior is studded with grains of quartz sand, and, on a vertical section through the oxide layer, sand grains are found to be abundant below the surface at depths as great as 3 mm., though such a depth is exceptional. In addition, old cracks are found completely filled, and others are coated on the walls with thin layers of mat to glossy, sometimes botryoidal, black, reddish-brown, deep red, or ocher-yellow deposits. Black is the usual color. This deposit is found also on parts of the surface, and between lamellae. Polished surfaces have a bright metallic luster. Dilute, acid copper sulphate reveals the presence of a number of particles of residual metal. These are confined almost entirely to the half of the oxide layer nearer the metal core. Most of them are within 5 mm. of it, and are less than a millimeter thick. The other dimensions are somewhat greater, and one wholly exceptional flake was spindle-shaped with axes 1.0 and 0.5 cm. in length.

When observed under the microscope without the copper coating, the particles appeared to be composed of a crowded cluster of metallic spheroids embedded in oxide. With the copper coating, they appeared to be homogeneous except for black spots. Either way, the edges were indistinct. At 100 diameters this indistinctness was seen to be due to the presence of numerous anastomosing threads of metal, penetrating, and disappearing into, the oxide. The microscope shows also that the homogeneous oxide consists of 2 substances differing in hardness and luster. These are arranged in a manner similar to that of the constituents of the unaltered metal. If the metal be regarded as a web of taenite inclosing particles of kamacite, then the darker and harder constituent is derived from taenite. The threads which extend out from the metal particles also represent taenite, which, because of its higher nickel content, is more resistant.

A sample of the oxide was analyzed by G. D. Van Arsdale, Assayer, of Pasadena, California. He reported:

Fe_2O_3	69.53%
FeO	14.99
NiO	4.55
Ignition loss	7.04
Loss at 110° C.	0.58
Insoluble	1.14
Total	97.83

Undetermined, minor constituents account probably for most of the remaining 2.17%. Most of the insoluble material appeared to be sand. No free metal was noticed, but FeO was somewhat high, as compared with that in other, similar, oxides, and the presence of free metal might be the reason. The ignition loss (regarded as due to combined water) was somewhat low as compared with that of other, analyzed, meteoritic rusts.

On comparing the nickel content (calculated as metal) of meteoritic rusts, with that of the unaltered metal, it is found that out of 15 analyses, all but 2 show a noticeable decrease in the nickel content of the oxide. The 2 exceptions show only a negligible change.[1] The nickel in the oxide of Monahans corresponds to 5.38% of the total metal. As the original metal contains 10.88%, there has been a decrease of 5.50%.

Evidence of a greater solubility of the nickel than of the iron of oxides has recently been presented.[1,2] The water in which the oxide was weighed for the specific-gravity determination was tested for nickel. After a few minutes' immersion, enough nickel had dissolved to give a positive result. Green and brown stains (indicating lawrencite) were found near metallic particles in one piece of oxide, but this piece did not figure in the preceding experiment.

Several stains of light green color were observed on parts of the oxide. On one piece where the green material was thicker, it formed a mammillated incrustation, emerald-green in color. Some of this was removed, care being taken to exclude as much of the oxide as possible. Under the microscope, some oxide was found. The green substance was transparent, ranged from bright green to yellowish-green, and was for the most part isotropic. A few of the yellowish pieces showed faint colors under crossed polaroids. Microchemical tests showed the presence of nickel, and probably carbonate. These properties are characteristic of zaratite. Very dilute acid was used in the hope that the oxide would not be dissolved, but a weak test for iron also was obtained.

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Taenite*

By John Davis Buddhue

Abstract

Taenite is really 2 substances. Of these, orthotaenite is a nickel-rich alloy whose composition is uncertain but seems likely to be Fe_2Ni. This formula is based on a statistical study of 26 analyses, and the fact that the iron-nickel frequency diagram has maxima indicative of this composition. The other constituent, metataenite, is a duplex substance composed probably of an intergrowth of orthotaenite and kamacite. In 9 (1 doubtful) out of 12 octahedrites examined, the taenite lamellae were composed of a dark central band of metataenite, with a band of orthotaenite on either side. The bands are either too thin or too thick to show this arrangement in the other 3 cases. The orthotaenite results from diffusion of nickel from the kamacite, while metataenite is a plessite-like residue left between the bands, but, because of a higher nickel content, is much finer-grained than plessite. Metataenite is, nevertheless, more soluble than orthotaenite. The black color is due to the removal of the more soluble constituent (kamacite) by the acid. The resulting surface is optically equivalent to a powder, and hence dark-colored. The separation of taenite lamellae from Canyon Diablo, Arizona,

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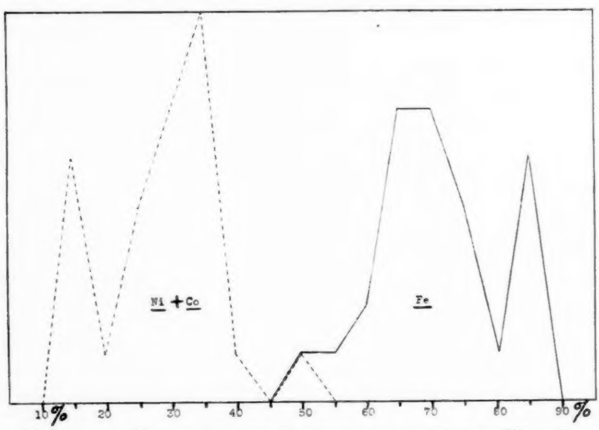
*Read at the Sixth Annual Meeting, Richmond, Virginia, December, 1938.

into 3 layers was accomplished, and the thicknesses of the whole lamella and the 3 constituent layers are given.

It has long been known that analyses of taenite do not agree, but range from FeNi to Fe_7Ni. Farrington seems to have been the first clearly to point out this circumstance.[1] The fact that only one of the analyses cited by Farrington contains much less iron than is required by the formula Fe_2Ni, combined with the fact that analyses giving ratios of $Fe:Ni = 1.7$ to 1.9 were made at a time when wholly satisfactory methods of separating nickel were not known, suggests that the iron content of taenite is at least twice the nickel content. Since several analyses are close to Fe_2Ni, S. W. J. Smith[2] suggested that the excess iron shown by some analyses may be due to an admixture of kamacite. That his suggestion may have some basis in truth is shown by the fact that Tschermak reported that the taenite of Ilimaes, Chile, consisted of a fine network of at least 2 bodies. This duplex nature of taenite has since been confirmed by Young[3] and by J. M. Robertson.[4] In a previous paper, I suggested that the nickel-rich alloy of the iron might be called *orthotaenite,* while the mixture of orthotaenite, and what is doubtless kamacite, might be called either *metataenite,* or just *taenite.*[5] I now think that the word *taenite* had better be reserved as a noncommittal term for either or both of the others. The composition of orthotaenite is still uncertain, but, inasmuch as many of the properties of iron-nickel (and also iron-cobalt) alloys have maxima, minima, or other notable features at, or very close to, $Ni = 34.4\%$, we are justified in assuming that something important is connected with the composition Fe_2Ni. This is the most frequent composition in Farrington's table, *op. cit.*[1]



FREQUENCY GRAPHS OF THE PERCENTAGES OF Fe AND Ni + Co FOR 26 ANALYSES OF TAENITE
(The ordinates are on an arbitrary scale.)

I have drawn (see the figure) frequency graphs of the percentages of iron and nickel + cobalt for all the analyses cited by Farrington, and 4 more which I have found in the literature, making 26 in all. The ordinates are on an arbitrary scale of frequency while the abscissae are graduated according to the class marks of the percentage interval (5%). Both graphs have 2 principal maxima, of which the primary ones are at the percentages required by Fe_2Ni. This I take to be the composition of orthotaenite. The secondary maxima correspond to Fe_6Ni, which I suppose represents the most frequent composition of metataenite, *i.e.*, about ⅔ orthotaenite and ⅓ kamacite.

Farrington gives the thickness of taenite lamellae as 0.03 to 0.25 mm. Nininger measured lamellae from the Nativitas, Tlaxcala, Mexico, iron, and found a range of 0.02 to 0.08 mm. with a mean of 0.034 mm. These were separated by the rusting of the kamacite. I have recently measured the thickness of 10 lamellae from the Canyon Diablo, Arizona, iron, and found a range of 0.025 to 0.126 mm. and a mean of 0.059 mm. Nininger's taenite was extremely elastic, while mine was flexible, but not elastic. My sample was separated by dissolving the kamacite in dilute acid. Nininger has mentioned that, under the microscope, taenite appears to be made up of 2 parallel bands.[6] He had previously succeeded in splitting the taenite plates of the Ogallala (Prior's "Brule"), Nebraska, meteorite into 2 plates.[7] I have examined 12 octahedrites, and in at least 8 have observed that the taenite is made up of not 2, but 3, parallel bands. This arrangement was not seen in Arispe, Mexico; Willow Creek, Wyoming; and Tazewell, Tennessee. The extreme thinness of the taenite in the first 2 cases, and its extreme thickness in the last, may be the reason. Even in the meteorites in which this arrangment was observed, it could not be seen in the thinnest lamellae. The meteorites in which this structure was observed were: Bear Creek, Colorado; Huizopa, Mexico; Henbury, Australia; San Angelo, Texas; Odessa, Texas; Xiquipilco (Toluca), Mexico; Clark Co., Kentucky; and Bristol, Tennessee. The last 2 have not yet been described. It was doubtfully observed in Bethany, South Africa.

The structure of a typical taenite lamella was found to consist of a central band of dark color, bordered on each side by a lighter band. This structure can be seen in Fig. 7 of Robertson's photomicrographs of Mbosi, Tanganyika Territory, Africa.[4] In the cases of Henbury, San Angelo, Odessa, and Bear Creek, it was observed that the black, central band was slightly depressed, probably because of greater solubility in the etching acid. In Odessa, the black color was not evident, but the depression was present. In most cases, the angle and intensity of the lighting were rather critical for seeing the structure to best advantage. Care was taken not to confuse the side bands with reflections from the sides of the lamellae, which, as a result of etching, stand above the kamacite.

As final proof of the 3-layered structure of taenite, it was found possible to split one lamella from Canyon Diablo into 3 layers. The central one measured 0.025 mm., and the side bands measured 0.013 mm. each. Another lamella was split into 2. The side band had the same thickness as that just given and the combination of the remaining side band and the black central band measured 0.033 mm. Other lamellae were observed to be separable into layers, but the resulting pieces were too small to measure with confidence. From the effect of a vacuum on the specific gravity of taenite, Cohen[8] deduced that it may have a lamellar structure. As an explanation of the 3-layered structure, I suggest that the side bands are composed of a nickel-rich alloy formed by the diffusion of nickel from the kamacite, because kamacite contains less nickel than the original solid solution. The central band represents what is left of the original solid solution. It is thus akin to plessite, but as it is probably richer in nickel, it has a finer structure.[5] That it consists of at least two substances is shown by Figs. 10 and 11 of Robertson's photomicrographs.[4] In other words, taenite lamellae, if not too thin, consist of a central core of metataenite, separated from the kamacite by thin bands of what is probably orthotaenite. In Fig. 7 of Robertson's photomicrographs,[4] only the black central band seems to have been regarded as taenite. The greater solubility of the dark core is correlated probably with a lower nickel content. The side bands are less soluble, because nickel is not soluble in dilute nitric acid. In the case of the Odessa meteorite, the dark color was missing, possibly because "unmixing" had not occurred. The dark color appears to be due to structure. The removal of the more soluble part of the metataenite forms a fine-grained structure, optically equivalent to a powder. Powdered metals are typically dark-colored, as, *e.g.*, platinum black.

I am not sure that the black metataenite corresponds to Pfann's microplessite. In a certain specimen of Xiquipilco, I found that wherever a taenite lamella widened considerably, the metataenite had a rather well-marked core of a yellowish-gray color. Indications of a micro-octahedral structure (such as is sometimes seen in plessite) were visible in some of these lamellae at ×440, the highest power available. I regard this structure as identical with Pfann's microplessite, although definite proof of the identity or separate existence of metataenite and microplessite must await further work.

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[6] *Am. Jour. Sci.* (5), **31**, 220, 1936.
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Abstracts of Three Papers Read at the Sixth Annual Meeting

By LINCOLN LA PAZ,

Department of Mathematics, Ohio State University, Columbus

[Following are the abstracts of three papers, nos. 2, 11, and 16 (see the "Report of the Sixth Annual Meeting" by Lincoln La Paz, Secretary *pro tempore*, *C.S.R.M.*, *P. A.*, **47**, 99-102, Feb., 1939), read at the Sixth Annual Meeting, Richmond, Virginia, December, 1938. These papers are expected to be published in full, either in the *C.S.R.M.* or elsewhere, in the near future.—EDITOR.]

(2) THE DISTRIBUTION OF THE RECOGNIZED METEORITES OF NORTH AMERICA. It is the purpose of the present paper to make a critical examination into the need for and the validity of the explanations which have been advanced to account for the observed lack of uniformity in the horizontal distribution of North-American meteorites. On the one hand, it is found that the forces conjectured by Farrington to give rise to a non-random infall of meteorites are not competent to produce such an effect. On the other hand, it turns out to be exceedingly unlikely that the most important meteoritic concentration in North America, *i.e.*, that in the Mt. Mitchell area, is the result of "mere chance." Arguments are adduced to show that the real cause of this concentration is the vast amount of small-scale placer mining which has been carried on in the southern-Appalachian gold field, the oldest placer ground in the United States. It is probable that the same explanation will account for the concentration of irons along the Mexican Cordilleras, the oldest gold-mining country on the North-American continent. On the contrary, the existence of such a minor meteoritic concentration as occurs in Kansas is found to be quite compatible with the hypothesis that the places of find of

the recognized meteorites of the Great-Plains region constitute a random set.

(11) Criteria for Estimating the Population of a Meteoritic Shower. Controversies such as the recent one between E. Stenz, F. A. Paneth, and L. J. Spencer, in regard to the number of meteorites which fell in the Pultusk, Poland, shower, serve to emphasize the untrustworthiness of published determinations of the total number, N, of meteorites (fragments and individuals) falling in meteoritic showers. It is the purpose of the present paper to deduce by use of the theory of probability, certain quite elementary criteria for the more exact appraisal of N. The methods developed have been tested under conditions simulating those met with in the field.

(16) The Age of the Pultusk, Poland, Stones. In 1932, F. A. Paneth determined the helium and radium content of a specimen of the Pultusk, Poland, shower. His measurements indicated that the age of Pultusk was about 5×10^8 years. This age has been generally regarded as too low to be acceptable. It is the purpose of the present note to show that, if A. Corlin's theory of the growth of meteorites in interstellar space is accepted and the long time-scale is adopted, then the age determination of Paneth is compatible with the observed average mass of the Pultusk "peas."

VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

The Variable Star S Persei: The peculiar variable S Persei has been under almost continuous observation for nearly 60 years. In spite of much study there is considerable controversy concerning its period, type of variation, *etc.* Various periods have been derived, from as small as 230 days to as large as 3360 days, with the most predominant value at 830 to 840 days. The range in magnitude has also been reported as variable, from slightly less than one magnitude to nearly five magnitudes. Some observers have considered the star a long-period variable with peculiarities; others have stated that it is of multiple-period type, similar to the semi-regular variables RV Tauri and DF Cygni.

That the star is peculiar can be readily seen when the observations are plotted on a scale sufficient to exhibit the variations as a whole. The light curve is shown in Figure 1, in which the time scale, abscissa, is much reduced over that ordinarily used for plotting long-period variables. Each point in the figure is the mean of all observations made in a ten-day interval.

It will be noted at a glance that the amplitude in brightness is decidedly variable, and that a dominant period of about 835 days is manifest throughout most of the curve. At times the range approaches five magnitudes, between 7 and 12, while at other times, especially during the years 1917 to 1920, the range barely attains one magnitude. Since 1927, it has been confined, in general, to between $8^M.9$ and $10^M.3$. The observed maxima and minima have presented vastly different forms, as would be expected with such great variations in amplitude.

It has been suggested that the varying form of light curve of S Persei is the result of two or more interfering waves. In 1904, H. H. Turner derived three values, namely 840, 1120, and 3360 days, with corresponding semi-amplitudes of $0^M.6$, $0^M.4$, and $0^M.4$; he also pointed out some analogies with the behavior of the sun-spot cycle.

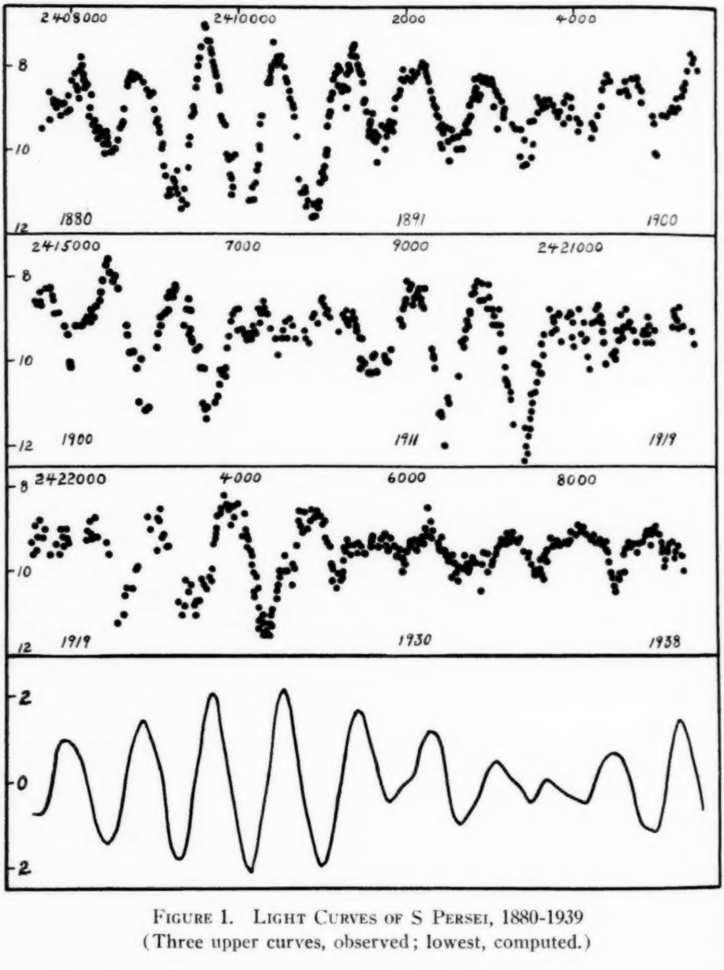

FIGURE 1. LIGHT CURVES OF S PERSEI, 1880-1939
(Three upper curves, observed; lowest, computed.)

Dr. T. E. Sterne has kindly examined the observed light curve of the star and derives two distinct periods, one of 810 days and the other of 916 days, with semi-amplitudes of 1.1 magnitudes each, which represent fairly well, in a general way, the star's variation. It is doubtful if any assigned periods will satisfy the observed curve exactly, because of probably inherent irregularities in the star. Sterne's values are decidedly better than those of Turner. The theoretical light curve computed from Sterne's values is reproduced in part in the lowest portion of Figure 1. It closely follows the observations plotted for the first 20 years. The possibility of a third long-term period is not precluded, in view of the general tendency for the median magnitude to decrease during the sixty years of observations. S Persei should more properly be termed a long-period variable with interfering periods, rather than a semi-regular variable.

SS Cygni Type Variables, 1937-1938: The light curves of twelve peculiar variables have appeared annually in *Harvard Observatory Circulars* for several years (1926 to 1936, inclusive). Since the individual observations of these stars have been published in recent issues of the *Harvard Observatory Annals* (Vol. 104; and Vol. 107, in progress), it seems hardly worth while to continue the annual reports in the *Circulars*, but better, instead, to summarize the results, mainly in graphical form, in these notes. Accordingly, we give here the results for 1937 and 1938 for

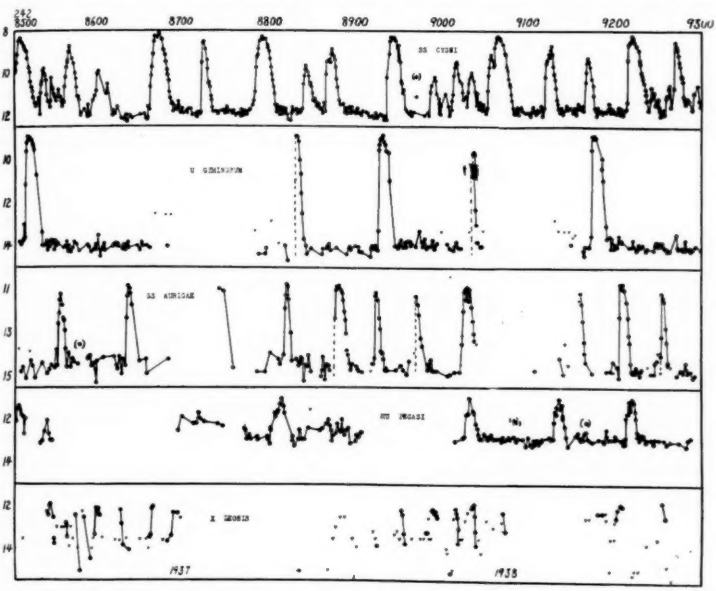

FIGURE 2. LIGHT CURVES OF FIVE SS CYGNI-TYPE VARIABLES, 1937-1938

SS Cygni, U Geminorum, SS Aurigae, RU Pegasi, and X Leonis; the last two have been recently added to the ranks of peculiar variables because they are now being observed more assiduously by A.A.V.S.O. members. The following table contains data of interest.

Variable	No. of Observations 1937	No. of Observations 1938	No. of Observed Maxima 1937	No. of Observed Maxima 1938	Mean Min. Mag. 1937	Mean Min. Mag. 1938
SS Cygni	1467	1386	8	9	11.63	11.49
U Geminorum	181	243	1	3	14.05	14.07
SS Aurigae	225	188	5	6	14.44	14.66
RU Pegasi	86	231	5?	3	12.87	12.87
X Leonis	57	47	7	8	15.0	15.1

SS Cygni was observed on 307 nights during 1937, and on 327 nights in 1938. The stars U Geminorum, SS Aurigae, and X Leonis were searched for on many nights and found to be below the limit of visibility of the telescopes used. Their light curves are shown in Figure 2, each point representing a daily mean.

It seems probable that one or two maxima of U Geminorum escaped observation during 1937, and that one was missed in 1938. That at least one maximum of SS Aurigae was not observed in 1937 and also in 1938 appears certain. Information pertaining to the observed maxima of RU Pegasi and X Leonis is not reliable, especially during 1937. The observed magnitude at maximum for RU Pegasi is not as bright as that given in published lists: that is, not brighter than magnitude 12.0, whereas the catalogues report the maximum magnitude as 9.0. The observed range for X Leonis agrees well with the published values.

Only by continuously observing such stars as these, and others of associated types, can we expect to obtain more definite information regarding possible ranges, lengths of cycles, and forms of maxima. SS Cygni has been the best studied of all the peculiar variables, with the result that we are in a better position to determine the nature of that star's activity. Its bright limiting magnitudes and location in the sky render it well suited for observation. Negative observations—those in which a star is reported as invisible or fainter than a certain magnitude—have value, although observations at actual minimum light are vastly more useful. Light curves of Z Camelopardalis- and R Coronae Borealis-type variables for these same years will appear in subsequent Variable Star Notes.

Spring Meeting of the A.A.V.S.O.: The twenty-eighth annual spring meeting of the American Association of Variable Star Observers will be held at the Observatory of the University of Michigan, Ann Arbor, Michigan, on May 19 and 20, 1939, with an excursion to the McMath-Hulbert Observatory scheduled for the 21st. This will be the first spring meeting of the Association to be held in the Central States, and a large group of members, heretofore unable to attend, are expected to be present.

Observers and Observations: An ever increasing group of observers who are members of the Milwaukee Astronomical Society continue to communicate to the A.A.V.S.O. valuable results from observations with a 13-inch reflector. Included in this group are Messrs. Albrecht, A. R. Ball, J. Ball, Jr., Diedrich, Halbach, Mages, Prinslow, Reggemann, Schmid, and Seibel.

The list of contributors for the month of March, with the number of stars observed and the number of estimates made by each, follows:

Observer	Var.	Est.	Observer	Var.	Est.
Ahnert	42	232	Diedrich	12	14
Albrecht	5	5	Economou	15	16
Baldwin	63	79	Escalante	121	121
Ball, A. R.	22	37	Fernald	49	76
Ball, J.	42	63	Ford	14	16
Bappu	30	120	Forrest	3	3
Bates	1	8	Gregory	39	41
Blunck	3	3	Halbach	69	74
Bouton	42	47	Harris	8	8
Brocchi	12	12	Hartmann	132	201
Buckstaff	5	9	Hiett	12	19
Callum	29	44	Hildom	33	86
Carpenter	22	23	Holt	96	205
Chandra	207	572	Houghton	38	38
Cousins	30	142	Howarth	14	14
Kelly	10	16	Jones	55	134

Observer	Var.	Est.	Observer	Var.	Est.
Kanda	2	10	Rademacher	3	4
Kearons	42	61	Recinsky	11	22
Kirkpatrick	33	44	Reggemann	14	14
de Kock	57	207	Rosebrugh	21	35
Koons	19	19	de Roy	14	66
Lange	2	2	Schmid	24	33
Loreta	164	553	Seely	12	18
Lundquist	3	9	Seibel	14	15
Mages	3	5	Sill	28	28
Maupome	45	48	Slocum	4	4
McLeod	14	23	Smith, F. P.	11	11
Meek	37	471	Webb	16	16
Palo	6	17	Weber	25	25
Parker	15	17	Williamson	7	8
Peck	10	27	Yamasaki	16	16
Peltier	83	104			
Prinslow	8	12	Total		4522

April 14, 1939.

Comet Notes

By G. VAN BIESBROECK

In the evening of March 17 a telegraphic message from the Central Bureau at the Harvard College Observatory announced two cometary discoveries.

The first one gave the recovery position of the expected PERIODIC COMET PONS-WINNECKE, which was obtained by H. Jeffers at the Lick Observatory:

1939 March 17.4671
Right Ascension, $14^h 36^m 11^s.7$; Declination, $+31° 20' 34''$
Magnitude 17 — Nucleus.

This faint object was found on plates taken with the Crossley reflector. The position is quite close to the prediction. A shift of 0.63 day earlier in the date of perihelion will account for the small discrepancy. The comet is brightening up rapidly. When last observed by the writer on April 9 the total brightness was estimated as 15. The comet showed a round coma of about 20″ diameter with a stellar nucleus in its center. The following ephemeris will locate the path during the month of May. From the expected brightness it is probable that moderate-sized instruments will suffice for bringing the object in view.

EPHEMERIS OF COMET PONS-WINNECKE

1939		α (h m)	δ (° ′)	M
May	1	14 58.9	+45 35	14.4
	9	59.1	46 35	14.0
	17	14 59.1	46 38	13.6
	25	15 0.3	45 25	13.1
	27	0.9	44 52	13.0
	29	1.6	44 12	12.8
	31	15 2.6	+43 24	12.7

The comet has received the preliminary designation 1939 *c*.

The second part of the announcement of March 17 referred to a new comet. It stated that a moving object at first considered as an asteroid and as such designated as 1939 CB was in reality of cometary nature. It was found on plates taken for the study of asteroids at the University of Turku (formerly Åbo) in Finland by the director Y. Vaisala. The position was given as follows:

1939 March 14.9215

Right Ascension, $9^h 37^m.1$; Declination, $+23° 7'$.

The brightness was estimated as 15^M with the additional information that this comet had a period of some 10 years. The object was first recorded by the discoverer as an asteroid:

1939 CB Feb. 8.80 $9^h 44^m.7$ $+15° 58'$.

It was afterwards recognized on plates taken at Turku on January 19 and from these rough data Y. Vaisala and Miss L. Oterma computed the preliminary orbit:

ELEMENTS OF ORBIT OF COMET 1939 *b*

Perihelion		= 1939 April 26.0	
Node to perihelion	ω	= 44° 22′	1950.0
Node	☊	= 135 30	
Inclination	i	= 11 4	
Eccentricity	e	= 0.6243	
Mean motion	μ	= 352″.8	

This comet has now been observed at several places. When first observed by the writer on March 20 a short tail about 1′ long in position angle 140° was at once apparent.

From a short arc P. Herget has computed elements similar to the above; he sends the following ephemeris for the month of May but this will require further correction:

EPHEMERIS OF COMET 1939 *b*

1939	α h m	δ ° ′
May 1	10 22.4	+23 36
9	36.1	22 32
17	50.7	21 14
25	11 6.0	+19 43

The comet is conveniently situated in the evening sky; its brightness is already decreasing so that its visibility is restricted to the larger instruments. The preliminary designation 1939 *b* will be used for this comet since the discoverer's information reached the Central Bureau earlier than the communication of Jeffers in regard to Pons-Winnecke Comet.

Many observations of COMET 1939 *a* (KOZIK-PELTIER) have become available and several new orbits have been computed. They differ very little from the elements given on p. 162 except that there is a slight indication of ellipticity corresponding to a very long period.

In May the search for two expected periodic comets might be successful. Both are to be looked for in the morning sky but will probably be quite faint.

EPHEMERIS OF PERIODIC COMET KOPFF

1939	α h m	δ ° ′
May 1	22 39.5	−2 36.2
9	22 56.1	−0 19.2
17	23 12.0	+1 55.4
25	23 26.8	+4 6.4
June 2	23 40.7	+6 12.1
10	23 53.7	+8 13.0

EPHEMERIS OF PERIODIC COMET BROOKS

1939	α h m	δ ° ′
May 14	23 4.5	−2 37
22	23 19.5	−1 9
30	23 34.6	+0 19
June 7	23 49.5	+1 46
15	0 4.4	+3 11
23	0 19.1	+4 32

The positions are referred to the equinox of 1950. The first object is now near its maximum brightness; the visibility of the latter will improve.

Williams Bay, Wisconsin, April 15, 1939.

Notes from Amateurs

Joliet Astronomical Society

Fifty members and friends of the Joliet Astronomical Society were guests of the Observatory Staff of the Elgin Watch Company on Tuesday evening, April 4.

Supervisor Ray S. Neidigh and Robert C. Miller conducted small groups through the observatory. The transit instrument was shown and the method of observing was explained. The chronograph was operated to show how each of the clocks is checked. The short-wave radio station under Mr. Miller's supervision sends time signals to all parts of the globe. Short-wave frequency bands are broadcast for the use of amateur operators.

The clock-room which houses the standard and sidereal clocks is kept within one-tenth of a degree of 85 degrees F. by automatic means. The method of controlling the clock rate by varying the air pressure was explained.

Attention was called to the many uses of time service by the factory and Chicago concerns.

Ben Hur Wilson arranged for the "open house" with the aid of Leonard Onsgard, program chairman, and transportation was in charge of E. M. Preucil, Paul Ohman, and Mr. Wilson.

Robert L. Price.

Joliet Junior College, Joliet, Illinois.

The National Capital Amateur Astronomers Association

The National Capital Amateur Astronomers Association, although not yet two years old, enjoys many advantages perhaps not available to societies elsewhere.

Washington is the home of a number of scientific institutions from which we have drawn able speakers who specialize in subjects interwoven with astronomy. These lectures have considerably widened our field of interest. Such men as these have generously given us the benefit of their time and effort:

Dr. Charles G. Abbot, Secretary, Smithsonian Institution.
Dr. F. R. Moulton, Secretary, American Association for the Advancement of Science.
Dr. Paul R. Heyl, Physicist, U. S. Bureau of Standards.
Rev. Dr. Paul A. McNally, Director, Georgetown University Observatory.
Dr. Fred E. Wright, Physicist, Carnegie Institution.
Dr. W. J. Humphreys, formerly Director, U. S. Weather Bureau.
Dr. Edgar W. Woolard, Meteorologist, Weather Bureau.

The Naval Observatory merits special mention. Much credit is due it for the success of our organization. Capt. J. F. Hellweg (Superintendent), Dr. Lloyd E. Wylie, Mr. John C. Willis, and Mrs. Isabel M. Lewis have presented lectures at our monthly meetings. Mr. U. S. Lyons who is our vice-president, conducts a class twice a month in the study of astronomy. On a few occasions we have been permitted to observe through the 12-inch, 26-inch, and 40-inch telescopes. The Observatory has also coöperated by allowing the amateurs to house their telescopes on the grounds where they are free to use them at any time.

Others who have given us the benefit of their study are: Messrs. James A. Hess, Honorary Director, Panama Canal Zone Observatory, N. Reed Warthen, Raymond G. DeFrees, and James Waldo Fawcett.

From more distant points we are proud to include as honorary members, Dr. Clyde Fisher, Curator-in-Chief, and Miss Dorothy A. Bennett, Assistant Curator of the Hayden Planetarium, and Mr. James Stokley, formerly Director of the Fels Planetarium.

Mr. Stephen Nagy, President of this Association is connected with the optical instrument division of the Navy Department and is well qualified to instruct a class of amateurs in telescope construction. Among 70 members there are about 23 telescopes, including a 5-inch Clark refractor, a joint possession of the Society.

Occasionally lectures on astronomy are presented by eminent scientists at the Carnegie Institution, Smithsonian Institution, and George Washington University, of all of which the amateur astronomers may take advantage.

Other outstanding sources containing a wealth of material for study and research are the Library of Congress and the Library of the Naval Observatory.

Where else could a group of amateur astronomers be so favorably stiuated?

Mabel Sterns, *Secretary.*

3007 Ordway St. N. W., Washington, D. C.

The New Haven Amateur Astronomical Society

The meeting of the N.H.A.A.S. on April 1 was held as usual with an attendance of twenty-six.

Mrs. Neale gave a very comprehensive and interesting account of the mechanics of the Annular Eclipse of April 19, and, by means of well-executed drawings and charts, explained this phenomenon and also the cycle of eclipses in a very illuminating manner.

The third in the series of radio broadcasts which the society is sponsoring will be given over Station WELI on April 27 and the subject is to be "The Appreciation of Astronomy" which will be broadcast in the form of a round table discussion.

Mr. Neale as chairman of the Telescope Group reported on the last meeting of the group at which nineteen were present when Mr. Kimball (President of the Society) gave a very good explanation and practical demonstration of the spectrum, he having four setups with various other appliances. He showed and explained the various lines characteristic of different chemicals which he burned in a Bunsen burner. His setup was quite adequate and his practical showing of spectrum lines was much appreciated. Much interest is always in evidence at these Telescope Meetings.

Mrs. Partridge (one of our society) addressed the group on the subject "Nebulae" and spoke at some length upon the uncertainty in the minds of the earlier astronomers as to the true nature of the nebulae, as the instruments of the earlier days were not powerful enough to properly examine these objects and the spectrum showed the nebulae to be composed of rare gas while other diffused nebulae showed stellar lines. Modern investigations have shown that nebulae as distinguished from ordinary star clusters fall into two classes having entirely different characteristics, *i.e.*, the galactic nebulae and the extra-galactic.

Those in the galactic system are of the diffuse and planetary type. The diffuse type are irregular in form and faintly luminous and yet some are dark and shut off a view of objects behind them. The planetary type are relatively small and as a rule have a star in their center. Mrs. Partridge illustrated her lecture with many lantern slides.

F. R. Burnham, *Secretary.*

New Haven, Connecticut, April 14, 1939.

General Notes

Dr. Arthur H. Compton delivered a lecture on the subject "Time and the Growth of Physics" at the New York University on April 26. This was the eighth of the James Arthur Lectures.

In 1926, the late James Arthur, of New Rochelle, New York, presented to New York University one of the largest and most comprehensive historical collections of clocks and watches in existence. The collection, in the Arthur Room of Gould Memorial Library on the campus at University Heights, consists of more than eighteen hundred time pieces and presents a story of the evolution of time keeping from the simplest sundial and hour glass to clocks having multiple dials and highly complicated mechanisms.

Mr. Arthur assembled the collection over a period of forty years, and at an expenditure of well over $150,000. Since the donation of the collection to the University about fifty clocks and two hundred watches, comprising many rare and valuable specimens, have been added to it. Many of the additions were donated, others purchased.

The will of the donor provided New York University in 1931 with a generous bequest to maintain and enhance the collection, and to provide an annual lecture on "Time and Its Mysteries."

The Rittenhouse Astronomical Society of Philadelphia held its regular meeting on Friday, April 14, 1939, in the Hall of The Franklin Institute. The program consisted of two addresses: (1) "The Philosopher Makes a Date," by Mr. Richard P. Lochner, Member of The Rittenhouse Astronomical Society, and (2) "Astronomical Stamp Collections," by Dr. Roy K. Marshall, Assistant Director of the Buhl Planetarium and Institute of Popular Science in Pittsburgh.

Before the meeting the President and Board of Governors invited the members of the Society and their friends to a dinner in honor of Mr. James Stokley, who is leaving Philadelphia to assume the position of Director of the Buhl Planetarium and Institute of Popular Science in Pittsburgh.

Notes from the Yerkes Observatory and the McDonald Observatory

The 82-inch mirror of the McDonald Observatory was installed in its mounting on Mount Locke on March 1, and several Yerkes astronomers were present to test the instrument and to conduct the first observations. Dr. Struve made a hurried trip to Mount Locke to conduct the final performance tests. Professor Van Biesbroeck obtained the first actual photographs in the prime focus and in the Cassegrain focus. The images were found to be small and round, and from visual observations Dr. Kuiper and Dr. Van Biesbroeck have estimated that the central nucleus of the star image has a diameter, in good seeing, of only 0″.05. After careful adjustment of the lever-system of the weight-supporting pads in the mirror cell the shape of the mirror was found by the knife-edge test to be very fine. This tends to confirm Dr. Plaskett's tests made in the shop in Cleveland.[1] Dr. Struve secured a number of spectrographic observations with the two-prism quartz spectrograph in the Cassegrain focus and the large glass spectrograph in the Coudé

[1] *Astrophysical Journal*, **89**, 84, 1939.

focus. Both combinations were found to work satisfactorily. A small mechanical change had to be made in the shop of the Yerkes Observatory in order to adapt the prime-focus camera to the special requirements of guiding from the rim of the tube. No tests have as yet been made of the slitless spectrograph designed by Mr. McCarthy.

Dr. Kuiper remained in Texas and has started a regular program of spectrographic observations (with a low-dispersion spectrograph) of faint proper-motion stars. The results obtained by him show that when the star image is completely lost within the slit, the gain in speed over the Yerkes 40-inch refractor in the photographic region corresponds to a factor of 5. This is exactly the predicted value.

The successful operation of the various spectrographs and cameras is due very largely to Dr. G. W. Moffitt who designed the prime-focus camera, the Cassegrain camera, and the Cassegrain spectrograph, and who supervised the construction of several instruments; to Professor G. Van Biesbroeck who had complete charge of the construction of the auxiliary instruments since October, 1937, who designed the mechanical parts of the Coudé spectrograph and of the slitless spectrograph, and who supervised the alterations of the prime-focus camera; and to Mr. Charles Ridell, expert instrument maker of the Yerkes Observatory, whose exceptional skill and untiring energy have, for almost seven years, been devoted to this project.

The Warner and Swasey Company may well be proud of the excellent mechanical performance of the 45-ton mounting; and Mr. C. A. R. Lundin, by the excellence of his optical work, has brought new honors to that distinguished line of practical opticians which started with the elder Clark and which included the younger Clark and Lundin—the father.

Since the McDonald Observatory has already been in operation for several years, the 82-inch telescope could be placed in operation as soon as it was completed. Dr. C. T. Elvey has devoted several weeks to the study of the mechanical and electrical features of the construction. As assistant to the director he will be in charge of the Observatory during the absence of the director who will continue also as the director of the Yerkes Observatory and will, therefore, be in residence on Mount Locke for approximately four months each year.

At the Yerkes Observatory, Dr. Morgan has continued his spectrographic and colorimetric observations of faint stars for the determination of their spectral types and absolute magnitudes. This work is efficient and fast. He plans to make it one of the major programs at the Yerkes Observatory. The parallax work has recently been resumed, under new viewpoints, by Dr. John Titus. Dr. Van Biesbroeck will continue his visual and photographic observations of double stars, asteroids, comets, etc.

Professor Albrecht Unsöld of the Institute for Theoretical Physics of the University of Kiel, Germany, has been appointed Visiting Professor at the Yerkes Observatory for three months, beginning April 1. Professor P. Swings of Liége, Belgium, will be at the Yerkes and the McDonald Observatories as C.R.B.* exchange professor for six months, beginning September 1. Dr. Daniel Popper has been appointed astronomer at the McDonald Observatory, beginning July 1, in place of Dr. Paul Rudnick who has accepted an instructorship at the University of Texas, in Austin. Mr. Walter Linke has replaced Mrs. Jessie Rudnick who has returned to the Yerkes Observatory in order to work for the degree of Ph.D. Dr. Karl Wurm left the Yerkes Observatory on April 1, at the expiration of his appointment as Visiting Assistant Professor, in order to return to the Potsdam As-

*Committee for Relief in Belgium.

trophysical Observatory. Professor Frank E. Ross returned to the Yerkes Observatory in April, after six months spent at the Mount Wilson Observatory. Dr. Louis G. Henyey has been awarded a J. S. Guggenheim fellowship for study and research at the University of Copenhagen with Professor Bengt Strömgren. He expects to leave for Europe on September 1. Miss Francis Sherman has been appointed assistant at the Yerkes Observatory in the place of Mr. Edwin Ebbighausen who has accepted a position at Wilson College, Chambersburg, Pennsylvania. On March 18 Professor Albert W. Recht of the University of Denver passed the examination for the degree of Ph.D. On the same date Miss Sherman passed the examination for the degree of M.S.

Dr. Thornton L. Page, who had been teaching astronomy on the campus of the University of Chicago since last October, came to the Yerkes Observatory in March, and Dr. Philip C. Keenan returned to Chicago in order to teach during the spring quarter. This exchange arrangement will make it possible for both men to devote a considerable part of their time to research.

Dr. Chandrasekhar's astrophysical monograph, "Introduction to the Study of Stellar Structure," was published by the University of Chicago Press in January. Professor Russell's monograph on "The Masses of the Stars" is scheduled for publication early in the summer, and arrangements are under way for a monograph by Dr. P. W. Merrill on "The Spectra of Long-Period Variable Stars."

In view of the dedication ceremony of the McDonald Observatory on May 5 and the astronomical symposium which has been arranged in connection with the dedication through the generosity of the Warner & Swasey Company, no special lecturers have been invited to the Yerkes Observatory during the summer. The regular staff will be somewhat depleted by the absence of Professors Kuiper and Chandrasekhar who have been invited to take part in the second international astrophysical conference in Paris during July. However, astronomers who wish to carry on research at the Yerkes Observatory during the summer, or graduate students who wish to register for advanced courses, will find a number of interesting problems and stimulating discussions.

OTTO STRUVE.

Yerkes Observatory, April 6, 1939.

Book Review

An Introduction to the Study of Stellar Structure, by S. Chandrasekhar. Astrophysical Monographs Sponsored by the *Astrophysical Journal*. (The University of Chicago Press, Chicago, Illinois. 509 pages. $10.00.)

This book on stellar structure appears as the second volume in the series of astrophysical monographs sponsored by the *Astrophysical Journal*. In the introduction the author states that in the monograph an attempt is made to develop the theory of stellar structure from a consistent point of view, and, as far as possible, rigorously.

The subject is limited to the theory of static stellar structure, as problems of stellar instability and stellar rotation have been entirely omitted. Within this scope, however, the author has aimed at completeness.

The book is divided into twelve chapters. Each chapter is followed by a section of biographical notes. The first chapter is devoted to thermodynamics. The presentation given follows Carathéodory. One finds here in a relatively small space a very clear exposition of the fundamental laws of thermodynamics. The fact that Carathéodory's axiomatic theory is presented for the first time in English enhances the importance of this chapter. Applications of the fundamental laws of thermodynamics of special importance in the theory of stellar structure are considered in the following chapter. The main topics are: thermodynamics of a perfect gas, uniform expansion of gaseous configurations, the virial theorem, and the thermodynamics of black-body radiation. In the third chapter the problem of stellar structure is attacked in a general way. No special assumptions are made except that the stars are in hydrostatic equilibrium. On this basis the order of magnitudes of the most important physical quantities characterizing the stellar interior is derived.

The fourth chapter deals with polytropic and isothermal gas spheres. Its one hundred pages make it the largest chapter in the monograph. In the words of the author, it represents, largely, the work of the great pioneers, Ritter, Lord Kelvin, and Emden. The introductory section on convective and polytropic equilibrium is of considerable interest, giving a rather detailed exposition of the physical reasoning that led, originally, to the consideration of polytropic equilibrium. Most of the space is, of course, devoted to the mathematical theory of the properties of the solutions of the Lane-Emden differential equations. The presentation is remarkably complete, and by unification and simplification the author has succeeded in making it relatively easy to follow. The bibliographical notes appended to this chapter are of special interest, containing a detailed analysis of the contributions of Lane, Ritter, Lord Kelvin, and Emden.

The first four chapters together form what the author aptly calls the "classical," in contrast to the "modern," part of the monograph. The "modern" part starts with a chapter on the formal theory of radiation. Beginning with the fundamental definitions, it leads up to the equation of radiative equilibrium, the equation of transfer in the stellar interior, and the equation of hydrostatic equilibrium. In the following chapter the problems of gaseous stars in hydrostatic equilibrium are attacked. First, general properties of stars in radiative equilibrium are discussed. Then follows an analysis of the stability conditions for radiative equilibrium and a discussion of the problems of convective equilibrium. Eddington's standard model is discussed in detail. The distribution of temperature, density, and pressure, the total energy, and the mass-luminosity relation are derived. More general models are discussed from the point of view of homology transformation. A special effort is made to bring out clearly the generality of the mass-luminosity relation. The chapter which follows deals with the concrete applications of the general results, discussed thus far, to the actual stars. It deals especially with the application of the mass-luminosity relation to the observational material on masses, radii, and luminosities of the stars. The theoretical calculation of the mean molecular weight and the opacity of stellar matter is considered in detail, and the method of determining the relative abundance of hydrogen, helium, and heavy elements from mass, radius, and luminosity described. The Vogt-Russell theorem is proved, and its bearing upon the chemical constitution of the stars discussed. Finally the conclusions concerning chemical constitution drawn from the Vogt-Russell theorem and the results derived from the mass-luminosity relation are correlated.

In chapter eight the theory of stellar envelopes, defined as that outer part of the stars which contains some suitably chosen small fraction of the mass (ten per cent, say), is considered. The author has been able to develop the theory of stellar envelopes to a high degree of completion. In order to appreciate the value of a theory of stellar envelopes it must be remembered that the envelope, as defined above, normally extends as far as half way from the surface to the center. The author makes use of the theory, partly to strengthen the results already obtained for normal stars, and partly to investigate, in an empirical way, the central condensation of very massive stars, for which the ordinary stellar model apparently breaks down. What is presented in this chapter is essentially the theory of a part of the stellar model that is characterized by mathematical simplicity. With a view to applications to the stars mentioned, for which the ordinary model is unsatisfactory, the theory will no doubt be extended so as to embrace the whole of that part of the star, about which our present physical information is reliable. In the following chapter some further stellar models are considered. The results obtained in previous chapters are partly confirmed and partly extended. One notes especially a discussion of the point-source model with constant opacity. This may be regarded as a first step toward the extension of the envelope theory mentioned above.

Chapter ten is devoted to quantum statistics. The discussion leads up to the complete equation of state of the electron gas, in particular that of the degenerate electron gas. The author expresses his regret that, owing to lack of space, it has proved impossible to make this chapter entirely self-contained. In fact, the fundamental Boltzmann relation connecting statistical mechanics and thermodynamics has to be taken for granted. Otherwise, however, the presentation is complete and clear. The next chapter deals with degenerate stellar configurations and the theory of white dwarfs. It contains sections on the gaseous fringe of a white dwarf, completely degenerate configurations, the discussion of the observational material and the theoretical mass-radius relation, the stellar criterion for degeneracy, the effect of radiation pressure, composite configurations, and partially degenerate configurations. In an appendix one finds extensive tables of white-dwarf functions, not previously published.

The last chapter is concerned with the problem of the origin of stellar energy. The author emphasizes that this chapter is on an entirely different level from the preceding ones, the subject being as yet in an early stage of development. An attempt is made to indicate some general trends in the current approach to the problem. This chapter should be quite useful as an introduction to a field that is, at the present moment, that one among the many fields of the theory of stellar structure which is in the center of interest.

As a whole, the monograph represents the outcome of an admirable effort, through which every argument in its five hundred pages, and every one of its more than two thousand equations has been brought to its proper place in a carefully planned design. In consequence, the monograph is not only a very valuable handbook for the astrophysicist, but should also prove extremely useful to the student of the subject. In fact, the developments, though sometimes naturally difficult always start right from the beginning with fundamental principles, and the full details are given.

The astrophysicist who works in the field of the theory of stellar structure has to accept the handicap that he cannot at every step of his developments compare theory and observation. On the other hand, he has the great advantage of dealing with objects which are, from a theorist's point of view, in many respects ideal. Therefore, while some of the results presented in the monograph may have to be modified in the course of future work, it appears that most of the content will be of permanent value.

The book has been very nicely produced, the printing, especially of the equations, is very satisfactory.

BENGT STRÖMGREN.

Copenhagen, Denmark, March 18, 1939.

POPULAR ASTRONOMY

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MAY, 1939

Correction.—*Instead* of the line above the figure on page 259, *read*

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The principal articles of this magazine, beginning with Volume **15** (1907), are listed in the INTERNATIONAL INDEX TO PERIODICALS.